Old Dominion University Research Foundation

A COMPARISON OF QUASI-STATIC INDENTATION AND DROP-WEIGHT IMPACT TESTING ON CARBON/EPOXY LAMINATES

FINAL REPORT

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Principal Investigator

Michael J. Douglas
Graduate Research Assistant

Project No. 191861 (NAG-1-2156)
(12-16-1998 to 12-15-1999)

(This Report contains material from the MS Thesis of M.J.Douglas)

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INTRODUCTION

This project was initiated to investigate the damage tolerance of polymer matrix composites (PMC). After a low velocity impact-such as the ones that can occur during manufacturing or service- there is usually very little visual damage. There are two possible methods to simulate foreign object impact on PMC: static indentation and drop weight impact. A static method for modeling low velocity foreign object impact events for composites can prove to be very beneficial to researchers since much more data can be obtained from a static test than from an impact test. In order to examine if this is feasible, a series of static indentation and low velocity impact tests were performed and compared. Square specimens of different sizes and thicknesses were tested to cover a wide array of low velocity impact events. Laminates with a 45 degree stacking sequence were used since this is a common type of engineering laminate. Three distinct flexural rigidities under two different boundary conditions were tested in order to obtain damage due to large deflections. Comparisons between static indentation and low velocity impact tests were based on the maximum applied transverse load. The dependent parameters examined were dent depth, back surface crack length, delamination area, and load-deflection behavior. Results showed that no distinct differences could be seen between the static indentation tests and the low velocity impact tests, indicating that static indentation tests can be used to simulate low velocity impact events.

RESULTS AND DISCUSSION

Introduction

Since the main purpose of the research being presented was to establish if quasi-static indentation testing was a true representation of a low velocity impact event, this chapter will address this issue by comparing the experimental results obtained in the low velocity impact testing to that of the quasi-static indentation testing. The impact testing will be discussed and then a comparison of the damage resistance of the material subjected to the two different events will be presented. Tables 1 and 2 list the specimens and the maximum loads used for comparison between impact and quasi-static testing. Once the specimens were tested, comparisons were made on the following:

- Dent Depth
- Crack Length
- Delamination Area

From these comparisons an understanding and analysis of the two types of testing procedures was achieved.

Clamped			
	Type of Event	Specimen ID#	Max Load N (lbf)
Flex: Support/Thickness Ratio=150			
8 Ply 6 inch Opening	Impact	616-15f	1930 (434)
	Static 0.05 in./min.	708-10f	1735 (390)
	Static 1.0 in./min.	720-08f	1899 (427)
16 Ply 12 inch Opening	Impact	616-04f	7108 (1598)
	Static 0.05 in./min.	720-04f	6993 (1572)
	Static 1.0 in./min.	720-05f	7357 (1654)
Medium: Support/Thickness Ratio=50			
8 Ply 2 inch Opening	Impact	728-11m	1036 (233)
	Static 0.05 in./min.	722-04m	1045 (235)
	Static 1.0 in./min.	722-05m	939 (211)
16 Ply 4 inch Opening	Impact	616-28m	3728 (838)
	Static 0.05 in./min.	708-02m	3705 (833)
	Static 1.0 in./min.	708-06m	3857 (867)
48 Ply 12 inch Opening	Impact	616-04m	26823 (6030)
	Static 0.05 in./min.	817-01m	26293 (5911)
	Static 1.0 in./min.	818-02m	28290 (6360)
Stiff: Support/Thickness Ratio=25			
16 Ply 2inch Opening	Impact	616-32s	3100 (697)
	Static 0.05 in./min.	722-02s	2918 (656)
	Static 1.0 in./min.	722-08s	2931 (659)
32 Ply 4 inch Opening	Impact	616-20s	7313 (1644)
	Static 0.05 in./min.	706-01s	7455 (1676)
	Static 1.0 in./min.	708-07s	7455 (1676)
48 Ply 6 inch Opening	Impact	727-05s	23100 (5193)
	Static 0.05 in./min.	720-01s	23429 (5267)
	Static 1.0 in./min.	817-03s	23389 (5258)

Table 1. ID Numbers and Maximum Loads for Clamped Specimens.

Simply Supported			
	Type of Event	Specimen ID#	Max Load N (lbf)
Flex: Support/Thickness Ratio=150			
8 Ply 6 inch Opening	Impact	727-10f	1873 (421)
	Static 0.05 in./min.	817.11f	1859 (418)
	Static 1.0 in./min.	817.04f	1859 (418)
16 Ply 12 inch Opening	Impact	728-06f	5400 (1214)
	Static 0.05 in./min.	818-06f	5458 (1227)
	Static 1.0 in./min.	818-04f	5667 (1270)
Medium: Support/Thickness Ratio=50			
8 Ply 2 inch Opening	Impact	728-03m	974 (219)
	Static 0.05 in./min.	819-02m	907 (204)
	Static 1.0 in./min.	819-08m	1059 (238)
16 Ply 4 inch Opening	Impact	727-12m	3701 (832)
	Static 0.05 in./min.	819-016m	3677 (827)
	Static 1.0 in./min.	819-10m	3777 (849)
48 Ply 12 inch Opening	Impact	61599-02m	23562 (5297)
	Static 0.05 in./min.	818-07m	23878 (5368)
	Static 1.0 in./min.	818-02m	28304 (6363)
Stiff: Support/Thickness Ratio=25			
16 Ply 2inch Opening	Impact	727-20s	2922 (657)
	Static 0.05 in./min.	819-04s	2918 (656)
	Static 1.0 in./min.	819-06s	2931 (656)
32 Ply 4 inch Opening	Impact	727-18s	9853 (2215)
	Static 0.05 in./min.	819-14s	9866 (2218)
	Static 1.0 in./min.	819-12s	10898 (2450)
48 Ply 6 inch Opening	Impact	727-02s	22121 (4973)
	Static 0.05 in./min.	817-08s	22726 (5109)
	Static 1.0 in./min.	817-06s	21476 (4828)

Table 2: ID Numbers and Maximum Loads for Simply Supported Specimens.

Drop Weight Impact Testing

All of the load versus deflection plots for the drop weight impact tests document the non-linear characteristics inherent to large deflection of plates. This can be seen in Appendix B. This non-linear characteristic behavior makes it very difficult to accurately predict mathematically how the material will behave when subjected to a transverse load. For that reason none of the classical laminate plate theory has been introduced for comparisons in this paper.

The impact duration versus stiffness ratio plots shown in figures 1 and 2, show that the stiffness ratio has a direct effect on the duration of the impact. The impact duration increased as the stiffness ratio increased (i.e. the specimen became more "flexible") for both boundary conditions. All stiffness ratios had overlap in the duration of impact data and little difference can be noted between the two sets of boundary conditions. It is apparent from the data that the duration of impact is dependent upon much more than simply the support to thickness ratios of the plates, otherwise the data for ratios of 25, 50 and 150 would be clustered together in well-defined groups. The only noticeable trend between the two boundary conditions occurs on the most flexible specimens with a stiffness ratio of 150. For these data, the simply supported boundary condition gives a slightly longer duration of impact than the clamped boundary condition as long as all other parameters are held equal.

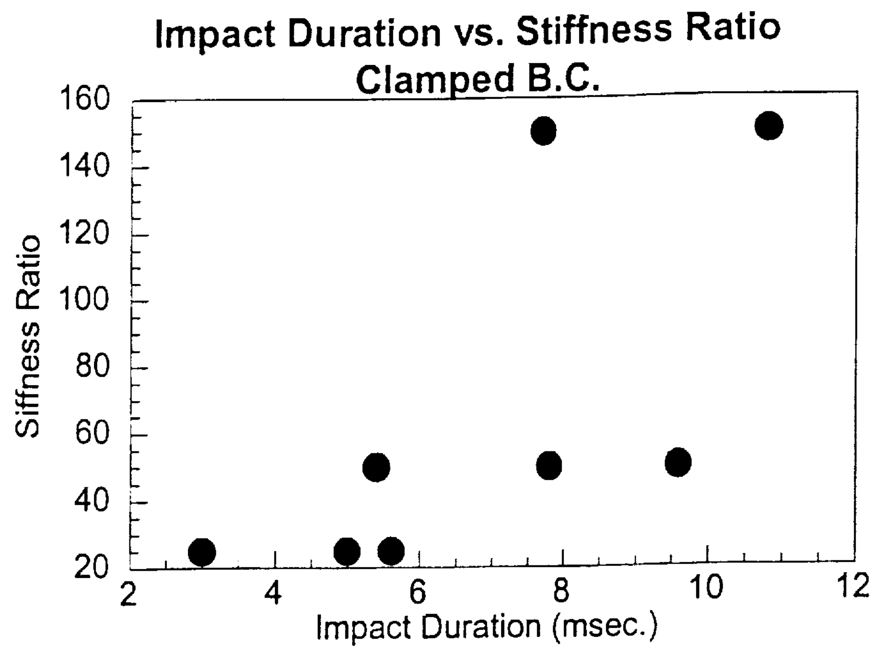


Figure 1: Impact Duration vs. Stiffness Ratio for Clamped Boundary Conditions

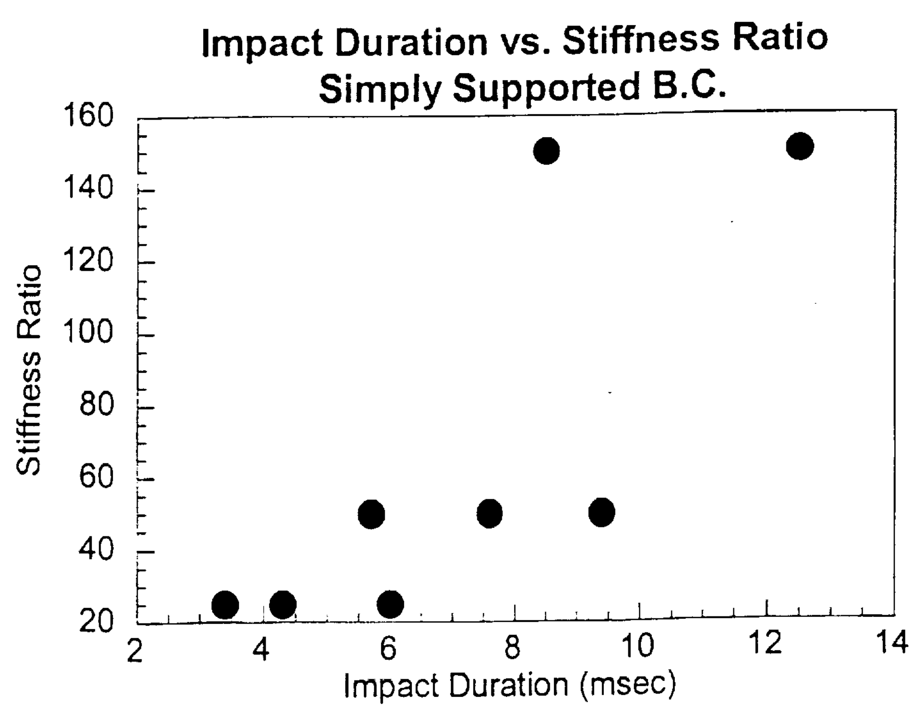


Figure 2: Impact Duration vs. Stiffness Ratio for Simply Supported Boundary Conditions

Quasi-Static Indentation Testing

Appendix C presents the Load-Deflection data generated for a limited number of the static indentation tests. The quasi-static test plots very different behavior characteristics depending in the stiffness ratio. For clarification, specimens ending in "f" indicate "flex" or a stiffness ratio of 150. Specimens ending in "m" indicate "medium" or a stiffness ratio of 50 and "s" indicates "stiff" or a stiffness ratio of 25.

For the "flex" specimens the Load-Deflection curves demonstrate the extreme non-linearity associated with large deflections of plates. The initial portion of the curve shows very little resistance to bending as a small load causes a large amount of deflection. However, as the membrane stresses begin to dominate, the amount of load needed to cause a given amount of deflection increases greatly. Little damage is noted in these specimens until the maximum load is reached. This suggests a damage mode associated with large bending stresses.

The "medium" specimens all show a "kink" in the initial loading portion of the Load-Deflection curves associated with initial damage. Higher shear stresses are developed in the stiffer specimens, which results in delamination type failures within the laminate. The curves are seen to be slightly non-linear until the initial damage is formed at which point the curves demonstrate more non-linearity.

The "stiff" specimens also have the initial load drop along the loading curve, which appears to be of a larger magnitude than in the "medium" specimens. This follows since the stiffer the specimens will develop larger shear stresses, which will release more energy when delamination does occur. Also of note is the change of stiffness at the very beginning of the Load-Deflection curve. This is associated with the contact stresses between the impactor and the plate. As the impactor first strikes the plate, it begins to "dent into" the specimen causing an indentation in the specimen. As the impactor goes deeper into the specimen, the contact stresses are spread out and the impactor stops indenting into the specimen.

Figure 3 show a drop weight impact test super imposed over a quasi-static indentation test. This figure shows that a fairly good agreement between the loads and deflections of the two types of test are achieved in the laboratory.

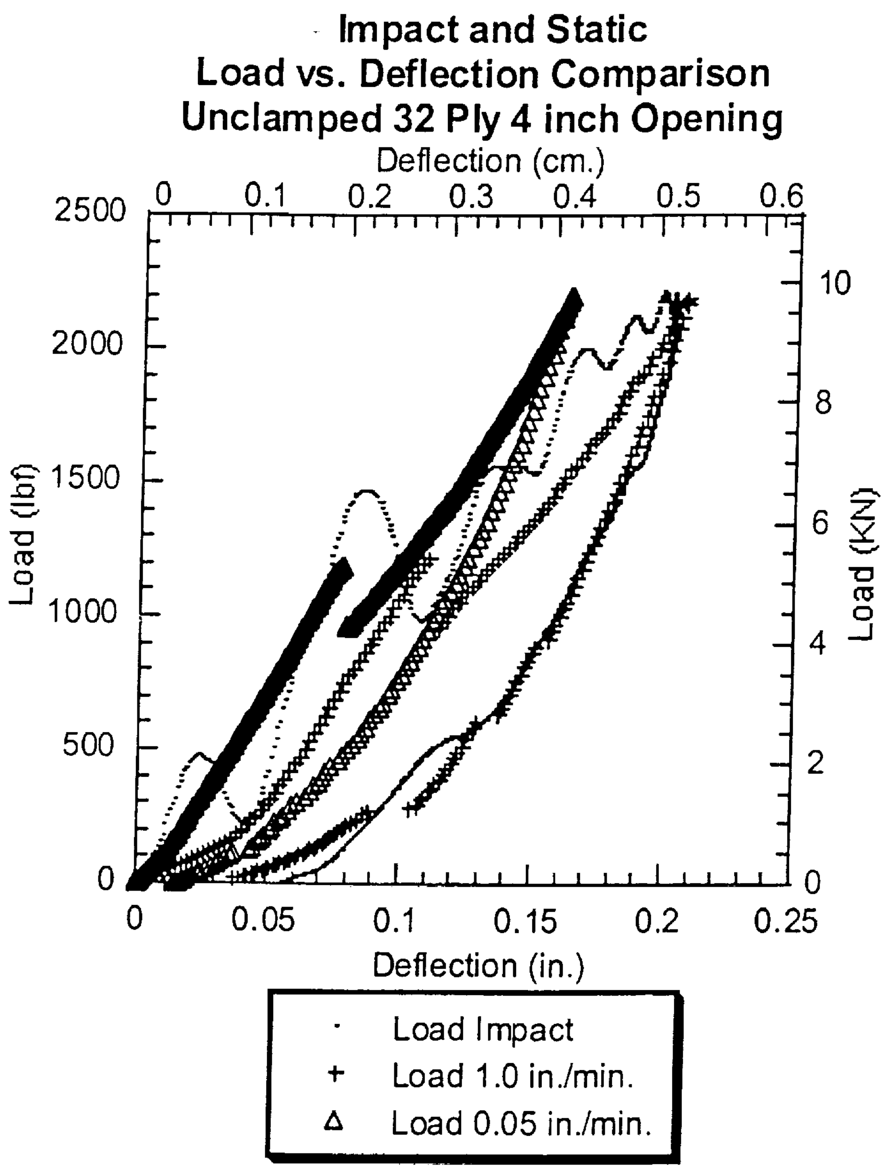


Figure 3: Load vs. Deflection Impact and Static Comparison.

Non-Destructive Evaluation

As mentioned earlier three different types of non-destructive analysis techniques were used. All non-destructive evaluation (NDE) analysis results are tabulated in appendix D. Since visible damage that occurs from an impact event is most easily measured, all analysis will be presented with the dent depth as the independent variable.

When an impact event occurs to a laminated component visual damage is not always apparent although there can be severe underlying damage. It has been proposed that if a correlation between the measurable dent-depth, usually the only visible damage, and underlying delamination or measurable crack length on the non-impacted surface then a damage resistance concern could be easily addressed. For this reason the dent depths were measured and documented for all specimens and used as the independent variable for all subsequent comparisons.

Crack Length

The specimens listed in tables 1 and 2 were used to generate the dent-depth versus crack length plots shown in figures 4 and 5. Figure 4 is for the clamped boundary condition and figure 5 is for the simply-supported boundary condition. For these two figures a least squares linear approximation was performed to find if any linear correlation between the two variables was present.

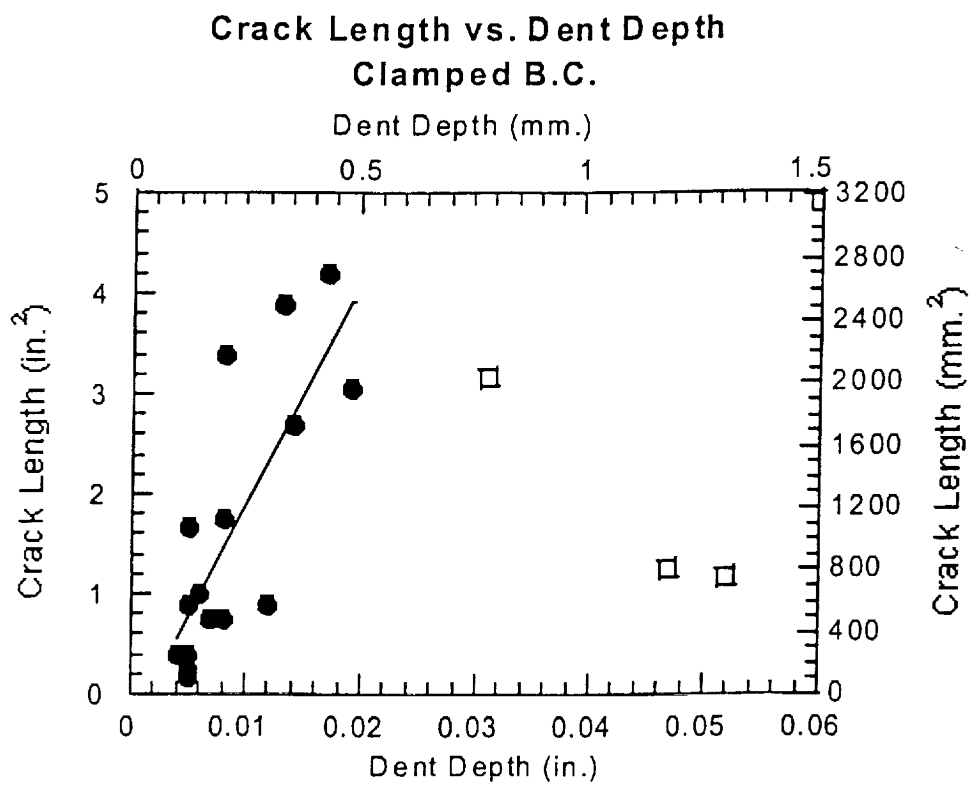


Figure 4: Crack Length vs. Dent Depth Clamped Boundary Conditions

In figure 4 the data represented by the open squares was not included for the least squares linear approximation. This was done because it fell outside of what was considered valid scatter bands. Equation 1 is the calculated linear approximation.

$$C = -0.347 + 224d \tag{1}$$

Where:

C is the crack length (in.)
D is the dent-depth (in.)

From equation 1 when the crack length (C) was set equal to zero and the equation solved for the dent-depth (d), a value of 0.0015 in. was calculated. This would suggest that a carbon/epoxy structure/component could sustain a low velocity impact event that produces a dent–depth of 0.0015 inches and not have any measurable crack length on the non-impacted surface.

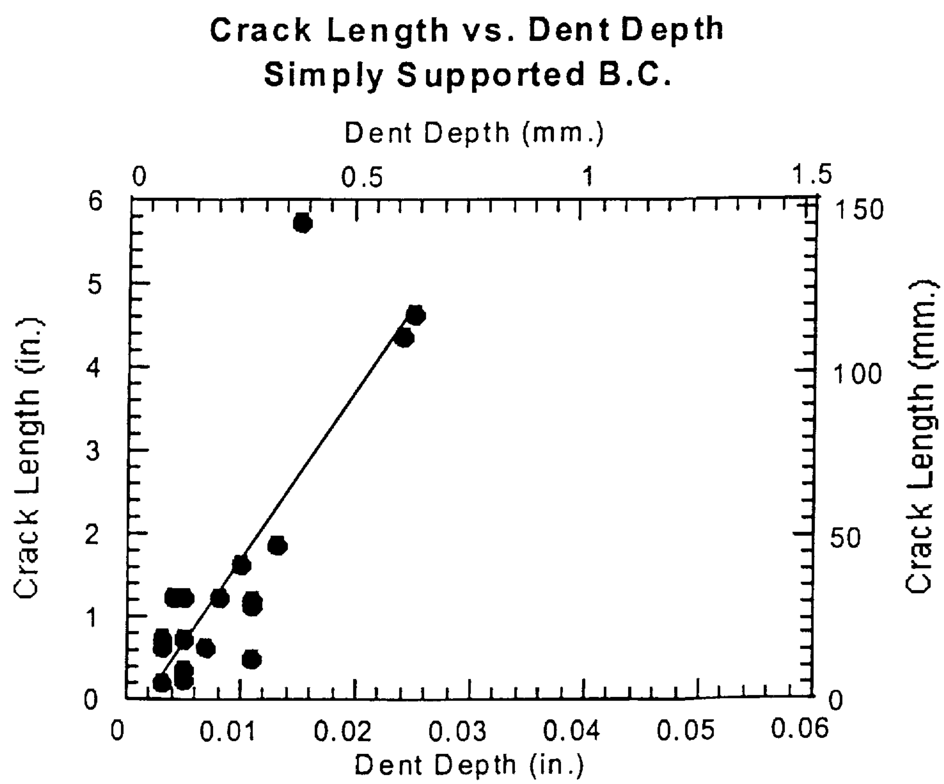


Figure 5: Crack Length versus Dent-Depth Simply Supported Boundary Conditions

For figure 5, equation 2 is the linear approximation calculated using the least squares approach as performed for figure 4.

$$C = -0.309 + 202d \tag{2}$$

Where:

C is the crack length (in.)
D is the dent-depth (in.)

If the same analysis is performed on equation as performed on equation the value for the maximum dent-depth without cracking was calculated to be 0.00153 in.

Although the two equations are in general agreement they do not take into account the stiffness ratio of the composite plates. As previously mentioned the stiffness ratio has a direct effect on the failure mode of the composite plates. Therefore a correlation needs to be found that is not so generalized as this approach.

Delamination Area

For the delamination area comparisons the same analysis will be performed as in the case of the crack lengths. Figures 6 and 7 are plots of delamination area versus dent depth for the clamped and simply supported boundary conditions, respectfully. The least squares linear approximations are presented in equations 3and7, however, the physical interpretations of these equations take on a different approach.

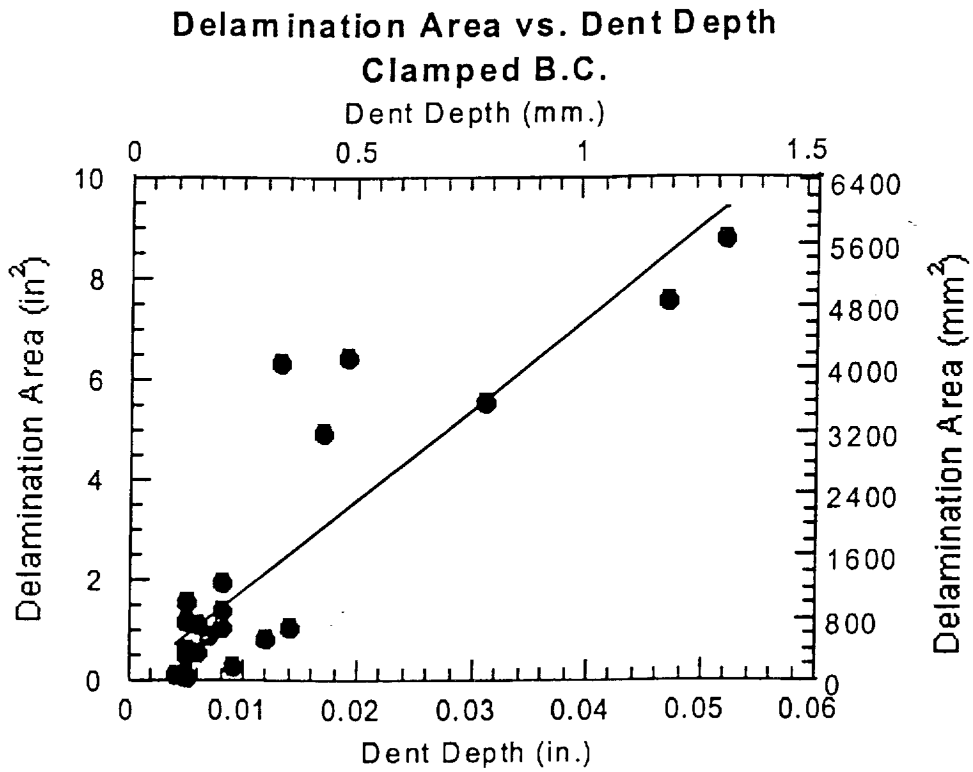


Figure 6:Delamination Area versus Dent-Depth Clamped Boundary Conditions

Equation 3 is the linear approximation to the data presented in figure 6.

$$A = 0.005 + 178d \tag{3}$$

Where:

A is the delamination area (in.^{2})
C is the crack length (in.)

Unlike the dent-depth discussion, in order to understand the physical meaning, if there is any, of equation 3, the dent-depth (d) was allowed become zero. Doing this leads to a value of delamination area (A) equal to 0.005 in^2.

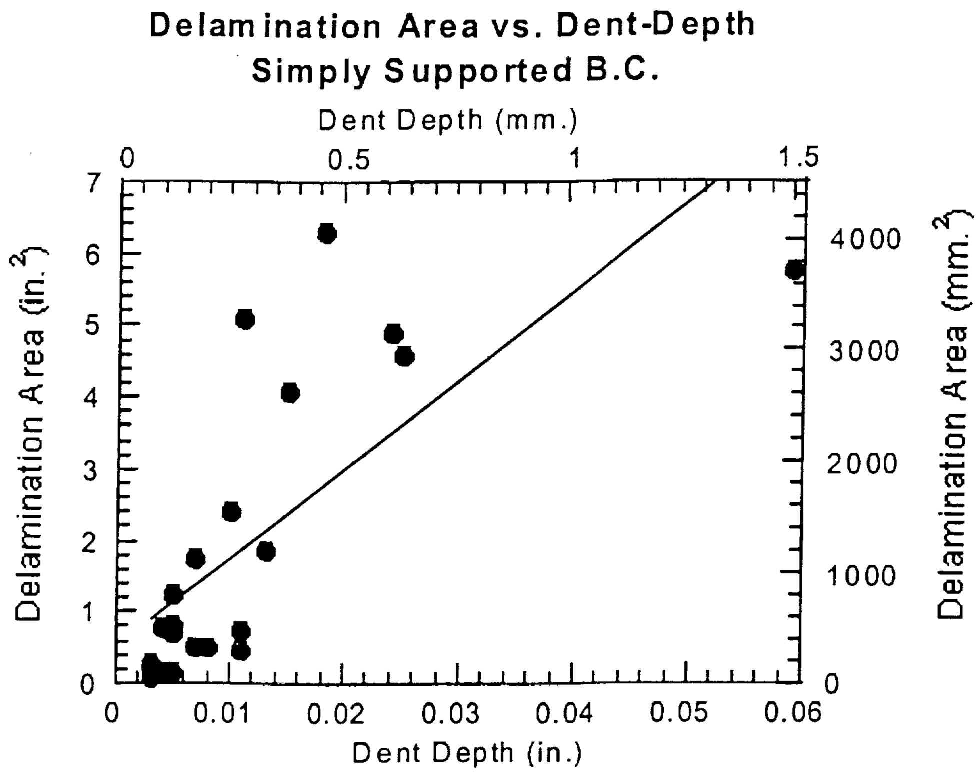


Figure 7: Delamination area versus Dent-Depth Simply Supported Boundary Conditions.

Equation 4 for figure 7

$$A = 0.52 + 124d \qquad (4)$$

Where:

A is the delamination area (in.^{2})
C is the crack length (in.)

Using the same analysis as performed on equation 3 a delamination area of 0.52 in.^{2} is found. This value is extremely large compare to the value for equation 3. One could argue that because of the simply supported boundary conditions this is

possible. The simply supported boundary conditions allow for a larger amount of flexure to the composite plate which in turn would produce more internal stress alluding to large internal delaminations for the same applied load.

This data implies that after an impact event has occurred to a carbon/epoxy component/structure, underlying damage can occur with no visual evidence. Again this analysis is overly simplified and a more in depth analysis needs to be found to better predict internal damage to laminated structures.

Comparison of Quasi-Static Indentation Testing and Drop Weight Impact Testing.

This section presents the main topic of this paper, which is "does a statically applied transverse load yield the same damage as a low velocity impact load of the same magnitude?" Using damage area as detected by x-ray analysis was deemed the most suitable method to do this since internal damage can be detected with this method. Figures 8-15 present delamination area as a function of applied transverse load for both low-velocity impacts and quasi-static loads of two rates. Each figure contains data for both clamped and simply supported specimens to test Jackson's assertion that the delamination area should be independent of this parameter.

Figures 8 and 9 present data for the case of "flexible" laminates (support/thickness ratio of 150). The open symbols represent the simply supported boundary condition.

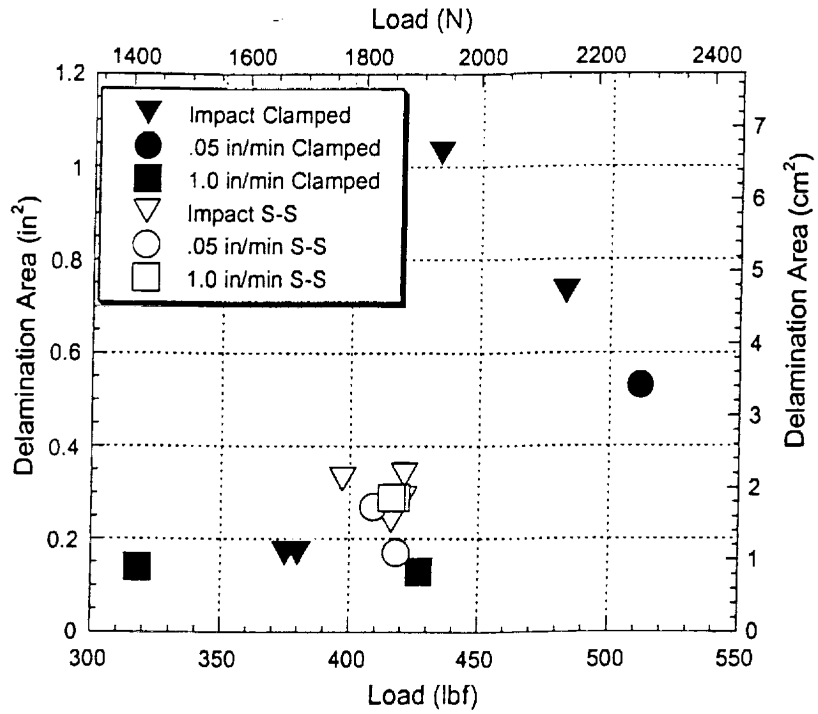


Figure 8. Delamination area versus Maximum Load for 8 ply specimens over 6 inch opening.

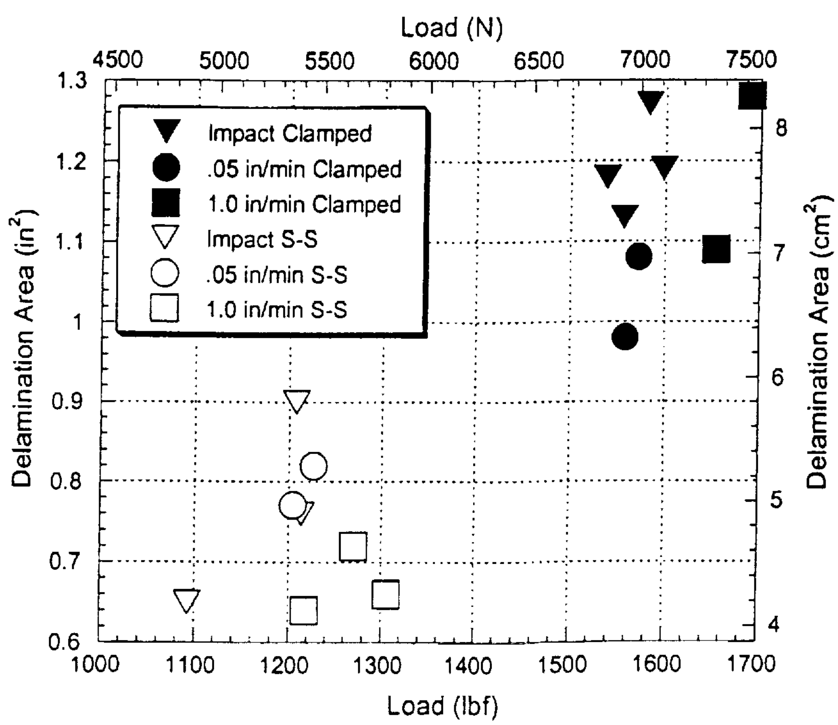


Figure 9. Delamination area versus Maximum Load for 16 ply specimens over 12 inch opening.

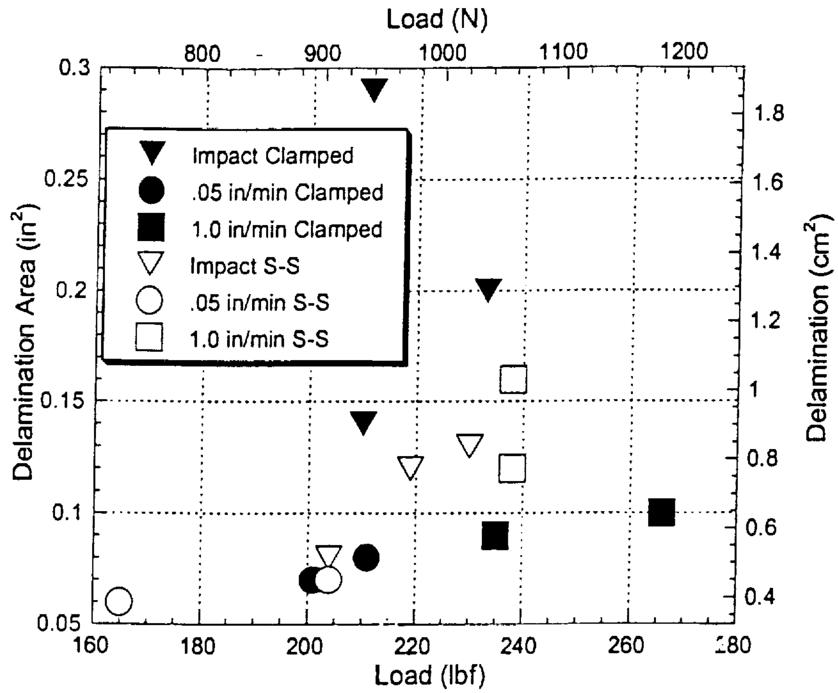


Figure 10. Delamination area versus Maximum Load for 8 ply specimens over 2 inch opening.

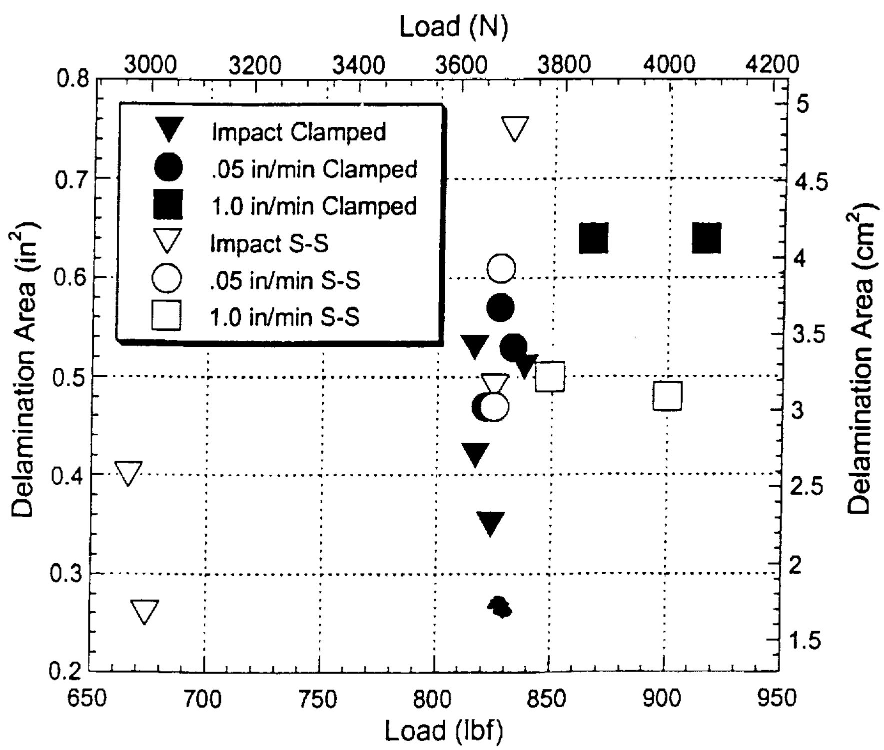


Figure 11. Delamination area versus Maximum Load for 16 ply specimens over 4 inch opening.

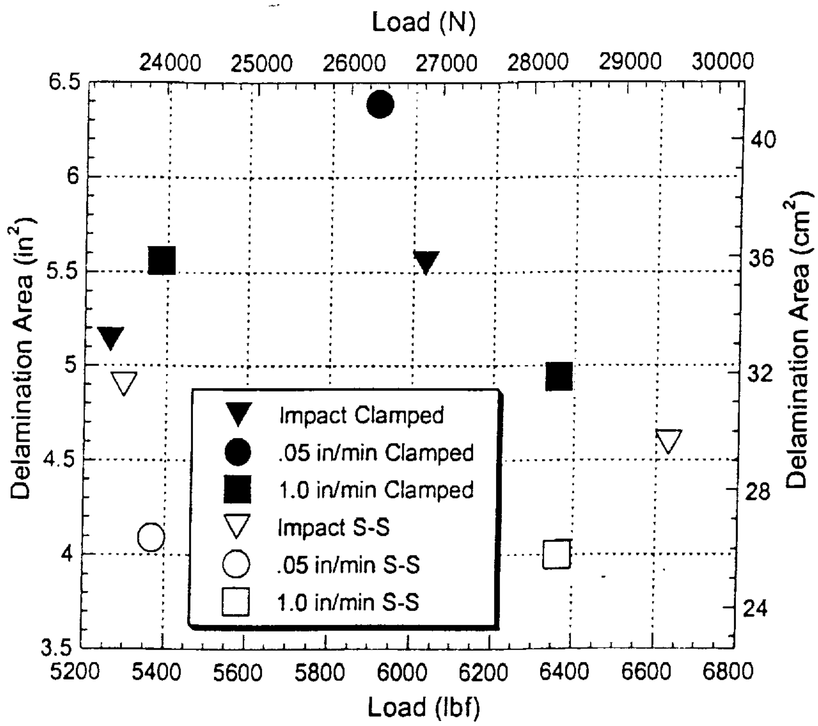


Figure 12. Delamination area versus Maximum Load for 48 ply specimens over 12 inch opening.

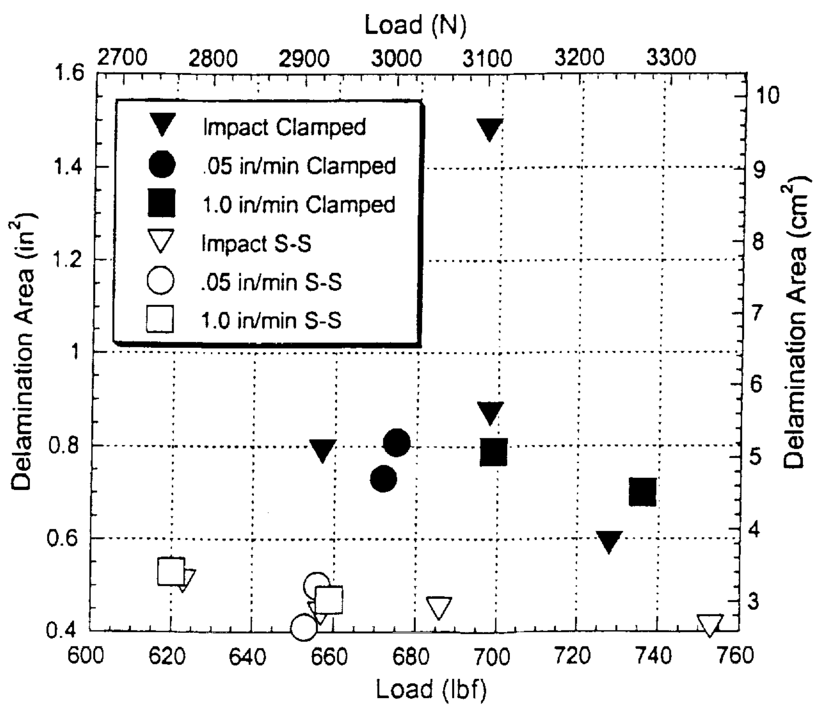


Figure 13. Delamination area versus Maximum Load for 16 ply specimens over 2 inch opening.

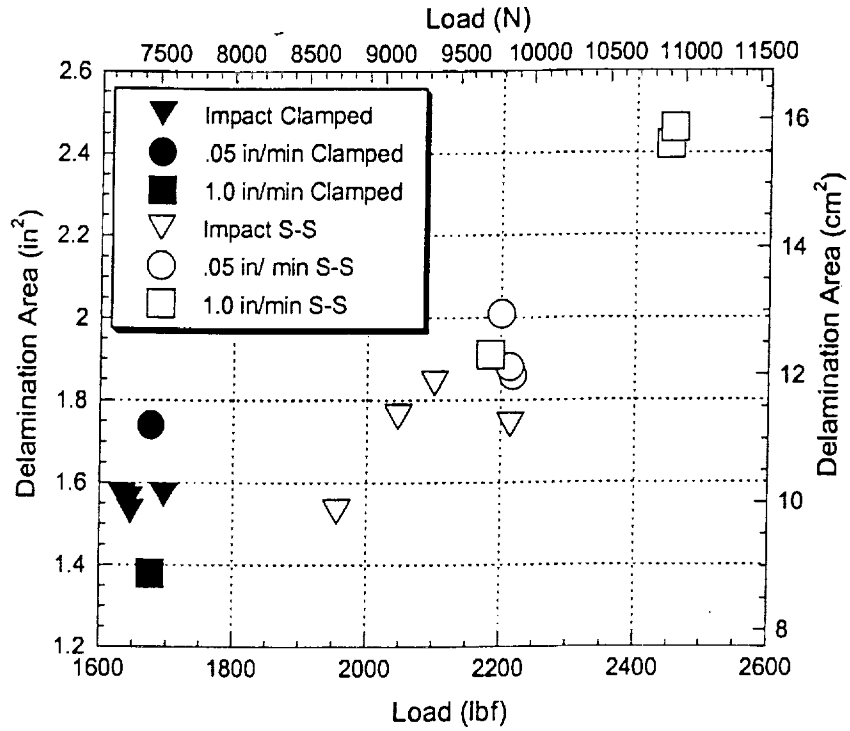


Figure 14. Delamination area versus Maximum Load for 32 ply specimens over 4 inch opening.

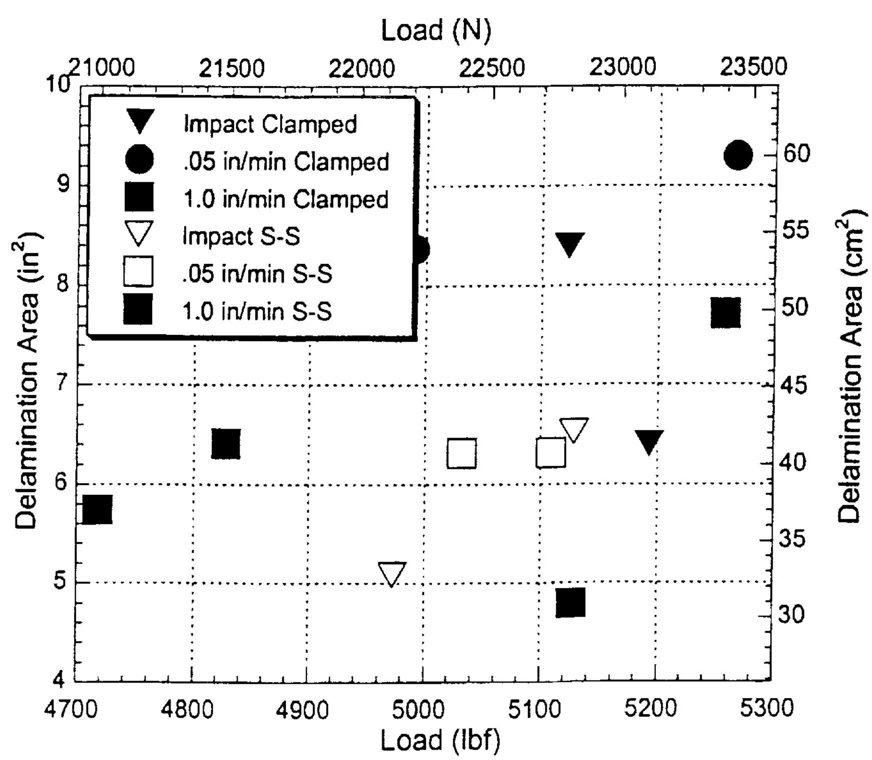


Figure 15. Delamination area versus Maximum Load for 48 ply specimens over 6 inch opening.

Figures 10- 12 present data for the case of "medium" laminates (support/thickness ratio of 50). The open symbols represent the simply supported boundary condition. Figures 13- 15 present data for the case of "stiff" laminates (support/thickness ratio of 25). The open symbols represnt the simply supported boundary condition

For the "flexible" laminates there is no difference between the impacted specimens and the ones tested quasi-statically at either rate. The effects of the boundary conditions show no difference for the 8 ply specimens supported over the 6-inch opening whereas a distinct difference is seen for the 16 ply specimens supported over the 12-inch opening. This difference is due to the clamped specimens being loaded to a higher level resulting in a larger delamination area.

The "medium" specimens have no distinct trends between boundary conditions or rate of loading. The impact test results fall in well with the static indentation tests in figures 10, 11 and 12. Boundary conditions also appear to have no effect on the maximum load versus delamination area.

Figures 13, 14 and 15 represent the opposite extreme from the "flexible" specimens in that the contact damage is the dominant failure mode. Again there is no discernable difference between impact and static indentation results. In figure 13, the simply supported specimens show slightly less damage for the same magnitude of maximum load than the clamped specimens, however this difference is slight.

Overall the low velocity impact tests can be represented by static indentation testing at rates of .05 and 1.0 inches per minute, regardless of specimen rigidity and boundary conditions. There is enough inherent scatter in both types of tests that all data fall within this scatter.

It must be kept in mind that these results are only valid for laminates of the $\pi/4$ type and laminates with different lay-ups or clumped plies may yield different results.

CONCLUSIONS

The following are the major conclusions of this study:

1. Static indentation tests *can* be used to represent low velocity impact events when the damage is compared by maximum transverse force. This is true of plates that experience flexural type damage, contact type damage and a combination of the two. Lay-ups other than of the $\pi/4$ type may not yield these same results.
2. Duration of an impact event is dependent upon the transverse stiffness of the plate. The more stiff the plate, the shorter the duration of impact. Boundary conditions have little effect on this behavior.
3. Much non-linear behavior is observed in the load-deflection curves for flexible laminates. As the laminate becomes stiffer, more linearity is seen and a distinct drop in load due to delamination becomes more pronounced.
4. Load-deflection plots of static indentation and low velocity impact are similar.
5. Dent depth results produce a great deal of scatter, which makes any conclusions concerning this parameter difficult.

APPENDEX A

Impact Specimen Id Number

Clamped Flex

Specimen ID #	Drop Height m.(in.)	Max Load N (lbf)	Impact Energy J (ft*lb)	Impact Velocity m\s (ft\s)	Max Deflction m. (in.)
8 ply on 6 in. platen					
616-15f	0.30 (12.00)	1930 (434)	7.54 (5.56)	2.42 (7.95)	No Data
616-16f	0.25 (10.00)	2148 (483)	6.35 (4.68)	2.22 (7.29)	0.897 (0.353)
616-17f	0.15 (6.00)	1673 (376)	3.74 (2.76)	1.71 (5.60)	0.762 (0.300)
616-18f	0.15 (6.00)	1668 (375)	3.75 (2.77)	1.71 (5.60)	0.782 (0.308)

16 ply on 12 in. platen					
616-01f	1.22 (48.00)	6841 (1538)	30.14 (22.23)	4.86 (15.94)	1.488 (0.586)
616-02f	1.22 (48.00)	6921 (1556)	29.65 (30.14)	4.82 (15.81)	1.491 (0.587)
616-03f	1.22 (48.00)	7037 (1582)	30.26 (22.32)	4.86 (15.96)	1.468 (0.578)
616-04f	1.22 (48.00)	7108 (1598)	30.26 (22.32)	4.87 (15.97)	1.435 (0.565)

Clamped Medium

Specimen ID #	Drop Height cm.(in.)	Max Load N (lbf)	Impact Energy J (ft*lb)	Impact Velocity m\s (ft\s)	Max Deflction m. (in.)
8 ply on 2 in. platen					
616-37m	12.70 (5.00)	1045 (235)	3.28 (2.42)	2.10 (6.89)	0.312 (0.123)
616-38m	12.70 (5.00)	939 (211)	2.32 (1.71)	1.76 (5.78)	0.014 (0.094)
728-09m	12.70 (5.00)	936 (210)	3.04 (2.24)	1.61 (5.28)	No Data
728-11m	12.70 (5.00)	1036 (233)	2.87 (2.12)	1.57 (5.14)	0.457 (0.180)

16 ply on 4 in. platen					
616-25m	35.56 (14.00)	3634 (817)	8.64 (6.37)	2.61 (8.55)	0.480 (0.189)
616-26m	35.56 (14.00)	3629 (816)	8.69 (6.41)	2.61 (8.57)	0.478 (0.188)
616-27m	35.56 (14.00)	3665 (824)	8.65 (6.38	2.61 (8.55)	0.483 (0.190)
616-28m	35.56 (14.00)	3728 (838)	8.85 (6.53)	2.60 (8.53)	0.483 (0.190)

48 ply on 12 in. platen					
61599-04m	119.38 (47.00)	26823 (6030)	155.44 (114.65)	4.71 (15.46)	1.257 (0.495)
61599-05m	119.38 (47.00)	23420 (5265)	156.54 (115.46)	4.73 (15.52)	1.171 (0.461)

Clamped Stiff					
Specimen ID #	Drop Height cm.(in.)	Max Load N (lbf)	Impact Energy J (ft*lb)	Impact Velocity m\s (ft\s)	Max Deflction cm. (in.)
16 ply on 2 in. platen					
616-29s	34.29 (13.50)	3239 (728)	8.39 (6.19)	2.57 (8.43)	0.4257 (0.1676)
616-30s	26.67 (10.50)	2922 (657)	6.35 (4.68)	2.23 (7.33)	0.3406 (0.1341)
616-31s	33.02 (13.00)	3105 (698)	8.07 (5.95)	2.52 (8.27)	0.4219 (0.1661)
616-32s	33.02 (13.00)	3100 (697)	8.03 (5.92)	2.51 (8.24)	0.4054 (0.1596)

32 ply on 4 in. platen					
616-20s	71.12 (28.00)	7313 (1644)	17.18 (12.67)	3.67 (12.05)	0.381 (0.150)
616-21s	71.12 (28.00)	7268 (1634)	17.38 (12.82)	3.69 (12.12)	0.386 (0.152)
616-22s	71.12 (28.00)	7544 (1696)	17.06 (12.58)	3.66 (12.00)	0.381 (0.150)
616-24s	71.12 (28.00)	7322 (1646)	17.45 (12.87)	3.70 (12.14)	No Data

48 ply on 6 in. platen					
727-04s	63.5 (25.00)	22788 (5123)	80.68 (59.51)	3.40 (11.15)	0.648 (0.255)
727-05s	63.5 (25.00)	23100 (5193)	80.68 (59.51)	3.40 (11.15)	0.635 (0.250)

Simply Supported Flex

Specimen ID #	Drop Height cm.(in.)	Max Load N (lbf)	Impact Energy J (ft*lb)	Impact Velocity m\s (ft\s)	Max Deflection cm. (in.)
8 ply on 6 in. platen					
727-06f	44.45 (17.5)	1850 (416)	10.21 (7.53)	2.93 (9.62)	1.18 (0.4647)
727-07f	44.45 (17.5)	1766 (397)	9.61 (7.09)	2.85 (9.34)	1.23 (0.4829)
727-08f	44.45 (17.5)	1850 (416)	10.20 (7.52)	2.93 (9.62)	1.34 (0.5255)
727-09f	44.45 (17.5)	1873 (421)	10.14 (7.48)	2.92 (9.59)	1.22 (0.4821)
727-10f	44.45 (17.5)	1873 (421)	9.65 (7.12)	2.85 (9.36)	1.24 (0.4865

16 ply on 12 in. platen					
728-05f	132 (52)	4862 (1093)	29.73 (21.93)	4.82 (15.80)	1.61 (0.6324)
728-06f	148.6 (58.5)	5400 (1214)	32.23 (23.77)	5.02 (16.46)	1.64 (0.6440)
728-07f	148.6 (58.5)	5373 (1208)	31.58 (23.29)	4.97 (16.29)	ND

Simply Supported Medium

Specimen ID #	Drop Height cm.(in.)	Max Load N (lbf)	Impact Energy J (ft*lb)	Impact Velocity m\s (ft\s)	Max Deflection cm. (in.)
8 ply on 2 in. platen					
728-02m	7.62 (3.00)	1023 (230)	1.78 (1.31)	1.23 (4.04)	0.2875 (0.1132)
728-03m	5.72 (2.25)	974 (219)	1.25 (0.92)	1.03 (3.38)	0.2314 (0.0911)
728-04m	4.45 (1.75)	907 (204)	1.08 (0.80)	0.96 (3.16)	No Data

16 ply on 4 in. platen					
727-11m	49.53 (19.50)	3723 (837)	11.88 (8.76)	3.18 (10.43)	0.6294 (0.2478)
727-12m	46.36 (18.25)	3701 (832)	10.55 (7.78)	2.30 (9.83)	0.5822 (0.2292)
727-13m	39.37 (15.50)	3670 (825)	8.27 (6.10)	2.65 (8.71)	0.5194 (0.2045)
727-14m	24.13 (9.50)	2998 (674)	5.57 (4.11)	2.18 (7.15)	0.4409 (0.1736)
727-15m	24.13 (9.50)	2963 (666)	5.33 (3.93)	2.13 (6.99)	0.3386 (0.1693)

48 ply on 12 in. platen					
61599-02m	119.38 (47.00)	23562 (5297)	157.64 (116.27)	4.75 (15.57)	1.415 (0.557)
61599-03m	119.38 (47.00)	29492 (6630)	157.83 (116.41)	4.75 (15.58)	1.422 (0.560)

Simply Supported Stiff

Specimen ID #	Drop Height cm.(in.)	Max Load N (lbf)	Impact Energy J (ft*lb)	Impact Velocity m\s (ft\s)	Max Deflection cm. (in.)
16 ply on 2 in. platen					
727-20s	52.71 (20.75)	2922 (657)	4.46 (3.29)	1.95 (6.40)	0.2774 (0.1092)
727-21s	20.32 (8.00)	2771 (623)	4.47 (3.30)	1.96 (6.42)	0.2809 (0.1106)
727-22s	16.51 (6.50)	3350 (753)	3.85 (2.84)	1.81 (5.95)	0.2705 (0.1065)
728-01s	16.51 (6.50)	3051 (686)	3.86 (2.85)	1.82 (5.97)	0.2664 (0.1049)

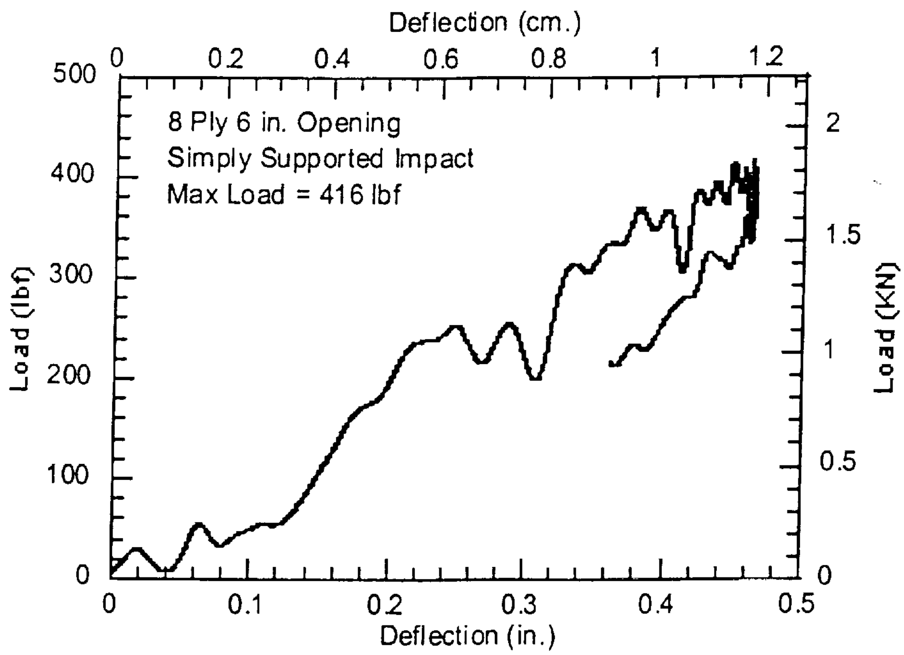
32 ply on 4 in. platen					
727-16s	104.14 (41.00)	8696 (1955)	22.22 (16.39)	4.35 (14.27)	0.4610 (0.1815)
727-17s	112.40 (44.25)	9101 (2047)	23.96 (17.67)	4.52 (14.82)	0.4821 (0.1898)
727-18s	124.46 (49.00)	9853 (2215)	27.05 (19.95)	4.80 (15.74)	0.5144 (0.2025)
727-19s	124.46 (49.00)	9346 (2101)	24.08 (17.76)	4.53 (14.86)	0.4782 (0.1883)]

48 ply on 6 in. platen					
727-02s	63.18 (24.88)	22,121 (4973)	79.20 (58.42)	3.36 (11.04)	0.6964 (0.2742)
727-03s	63.18 (24.88)	22,810 (5128)	82.56 (60.89)	3.39 (11.12)	No Data

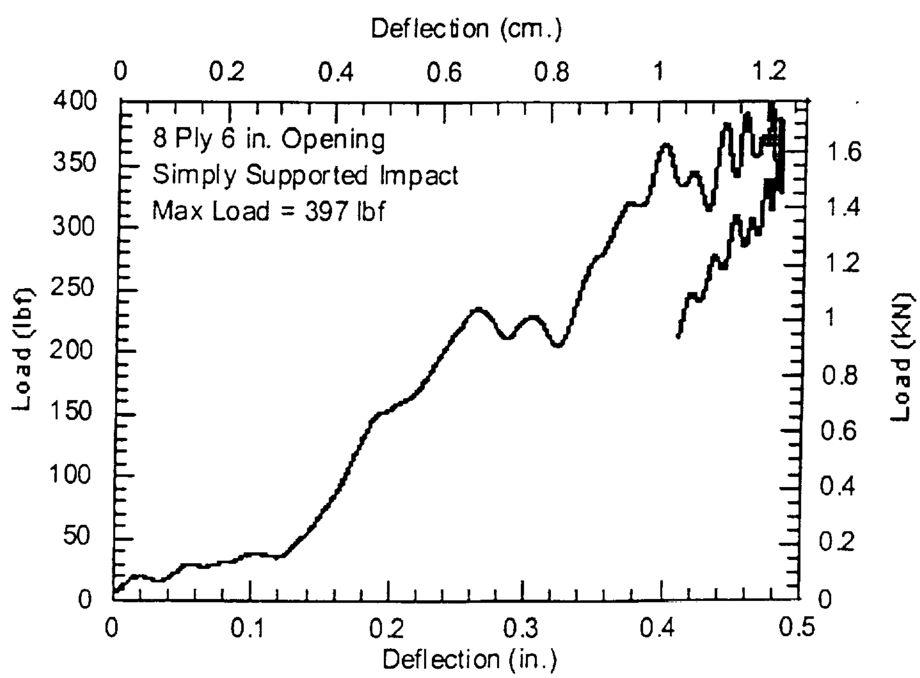
APPENDIX B

LOAD VERSUS DEFLECTION PLOTS FOR IMPACT SPECIMENS

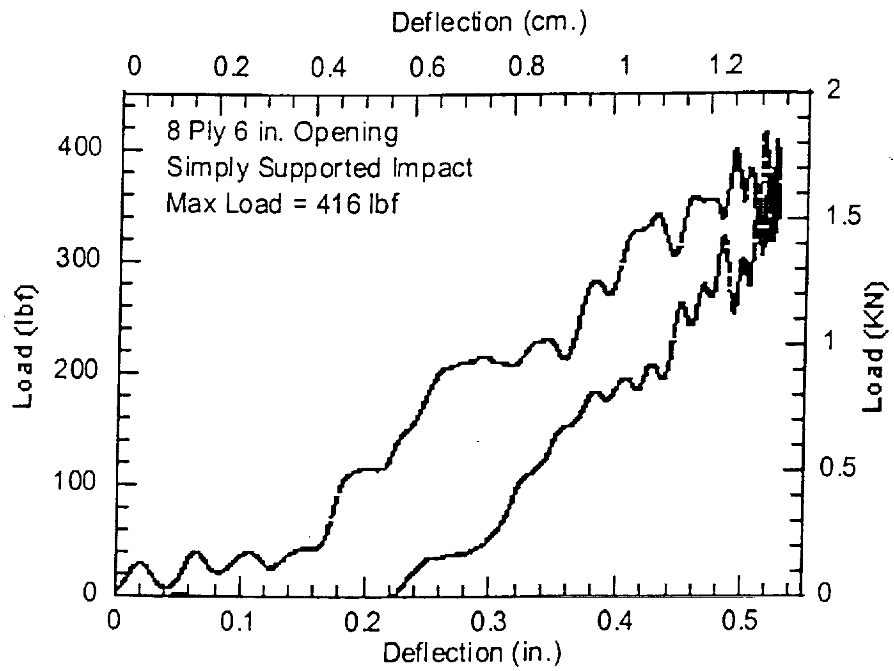
Load vs. Deflection
Specimen 727-06f



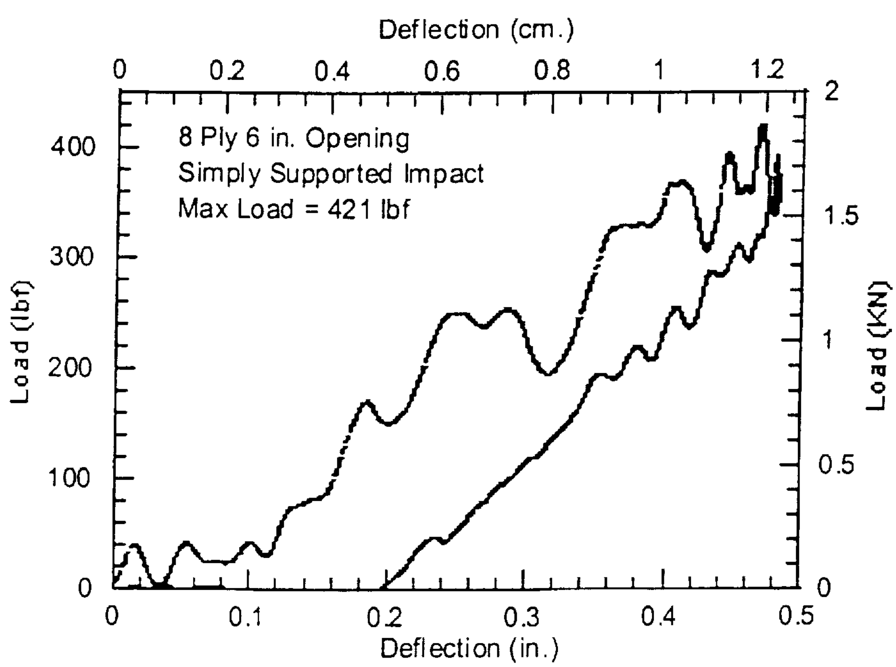
Load vs. Deflection
Specimen 727-07f

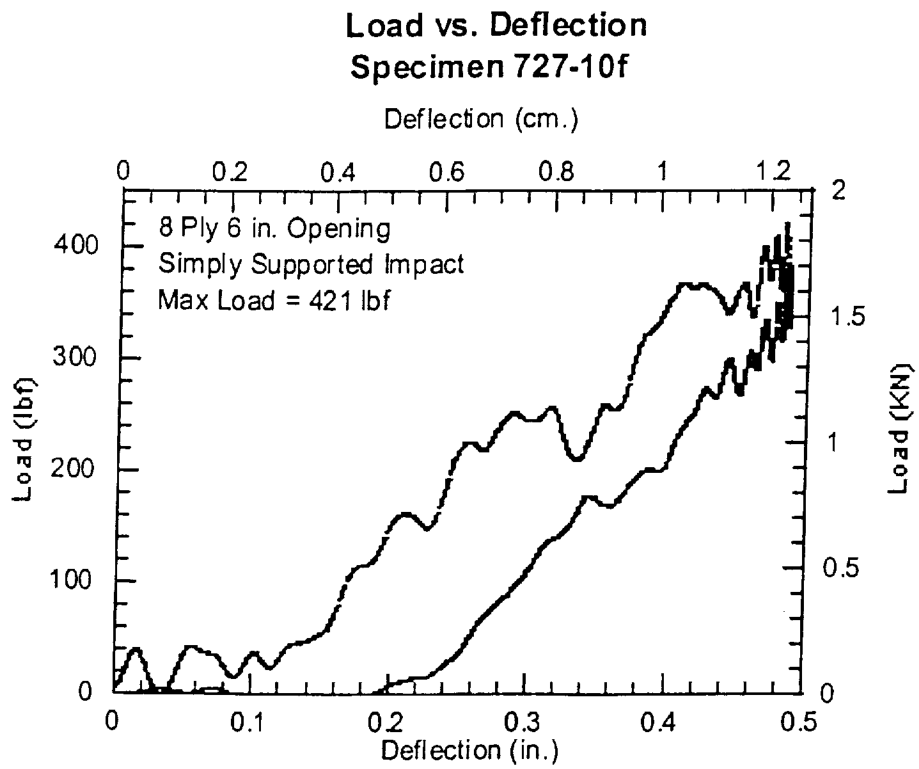


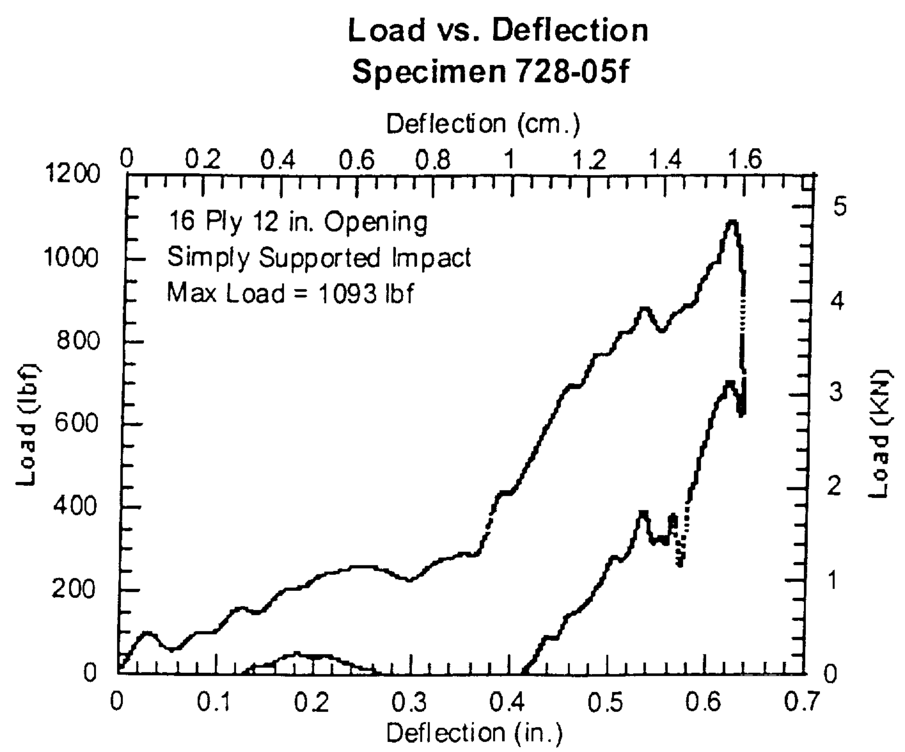
Load vs. Deflection
Specimen 727-08f

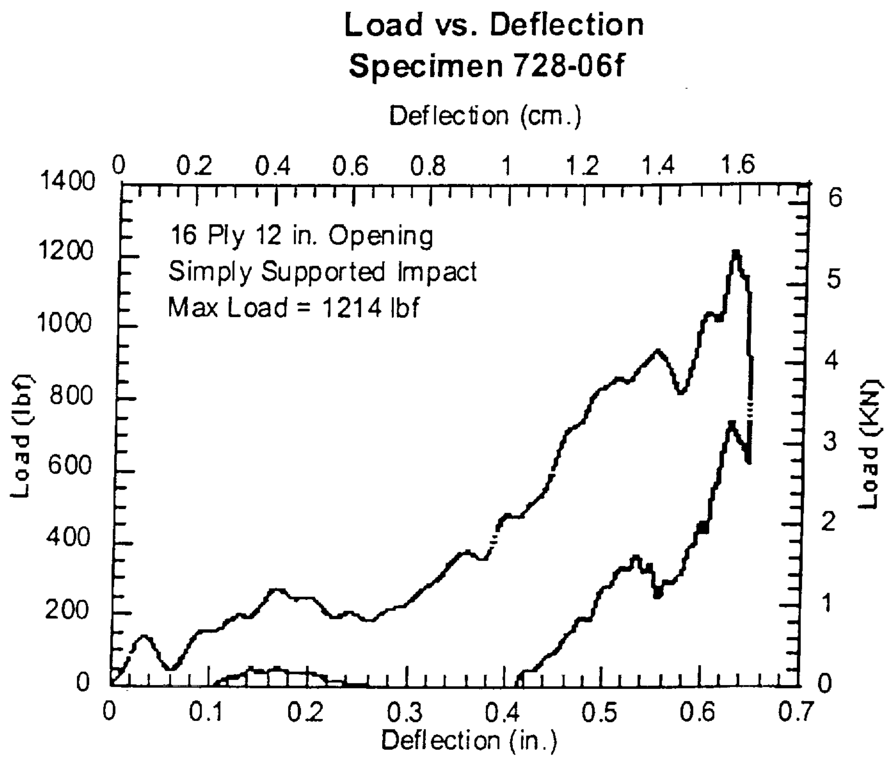


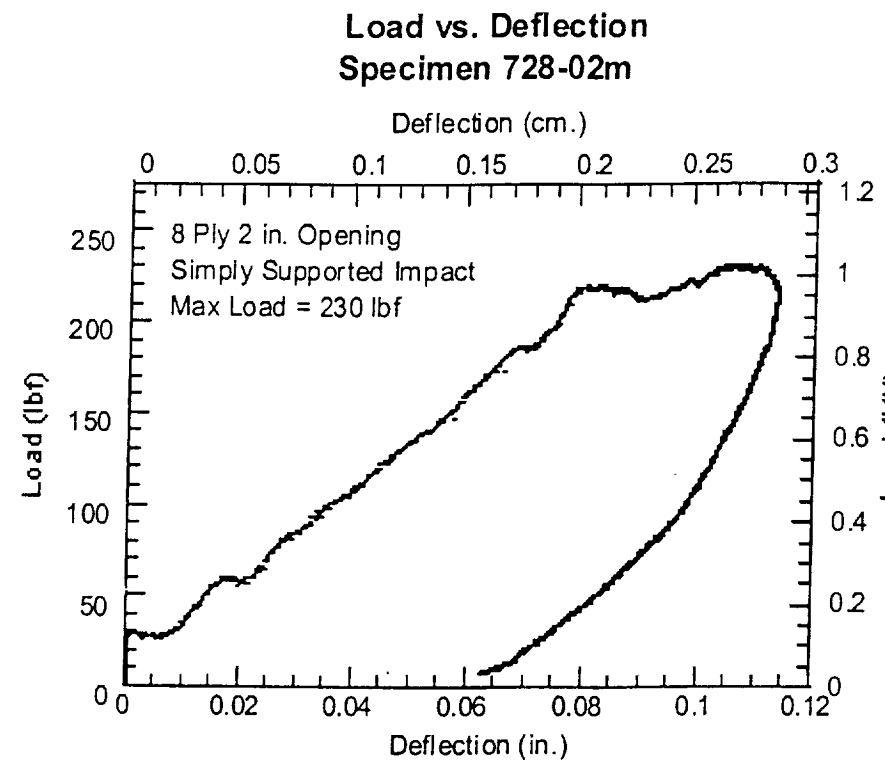
Load vs. Deflection
Specimen 727-09f



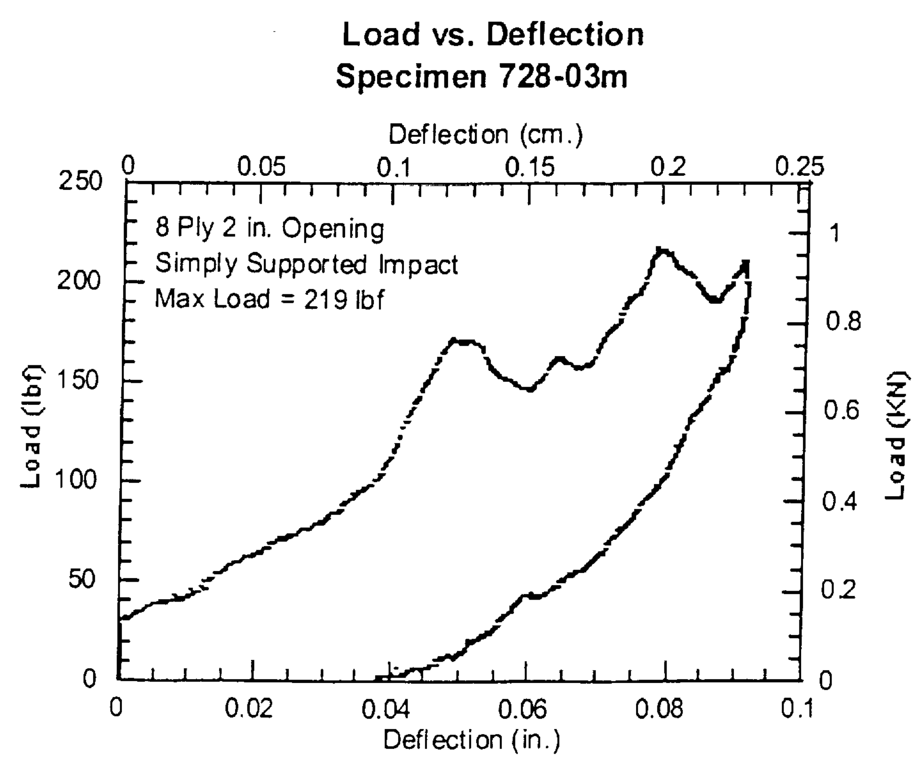

Load vs. Deflection
Specimen 727-10f
Deflection (cm.)
0
0.2
0.4
0.6
0.8
1
1.2
8 Ply 6 in. Opening
Simply Supported Impact
Max Load = 421 lbf
Load (lbf)
400
300
200
100
0
Load (KN)
2
1.5
1
0.5
0
0.1
0.2
0.3
0.4
0.5
Deflection (in.)


Load vs. Deflection
Specimen 728-05f
Deflection (cm.)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
16 Ply 12 in. Opening
Simply Supported Impact
Max Load = 1093 lbf
Load (lbf)
1200
1000
800
600
400
200
0
Load (KN)
5
4
3
2
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Deflection (in.)

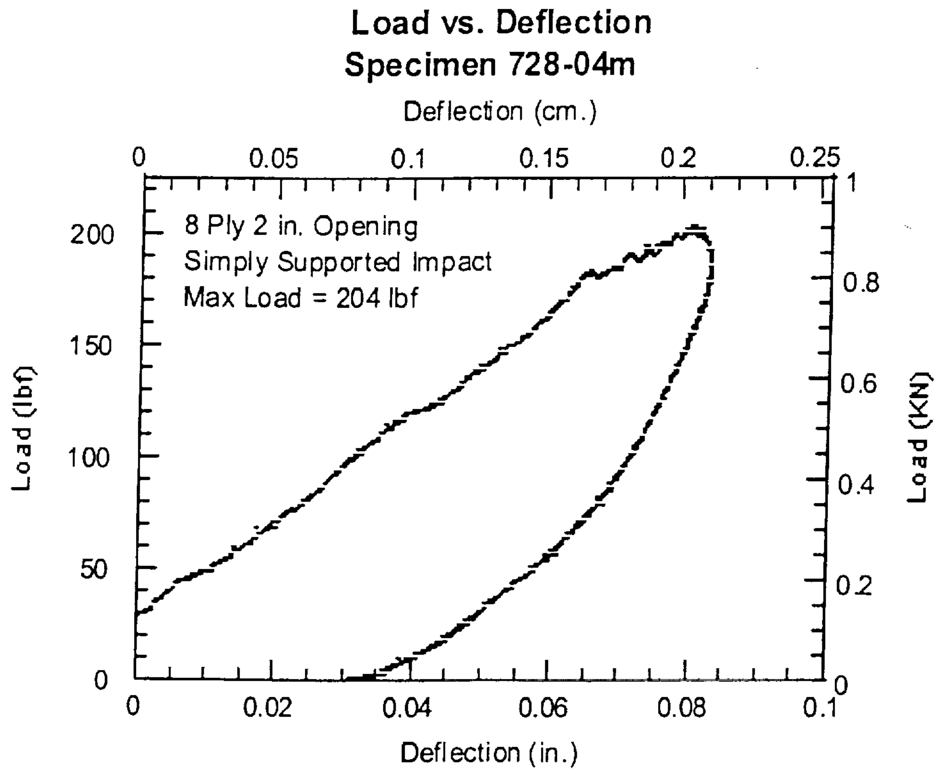

Load vs. Deflection
Specimen 728-06f
Deflection (cm.)
16 Ply 12 in. Opening
Simply Supported Impact
Max Load = 1214 lbf
Load (lbf)
Load (KN)
Deflection (in.)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1400
1200
1000
800
600
400
200
0
6
5
4
3
2
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

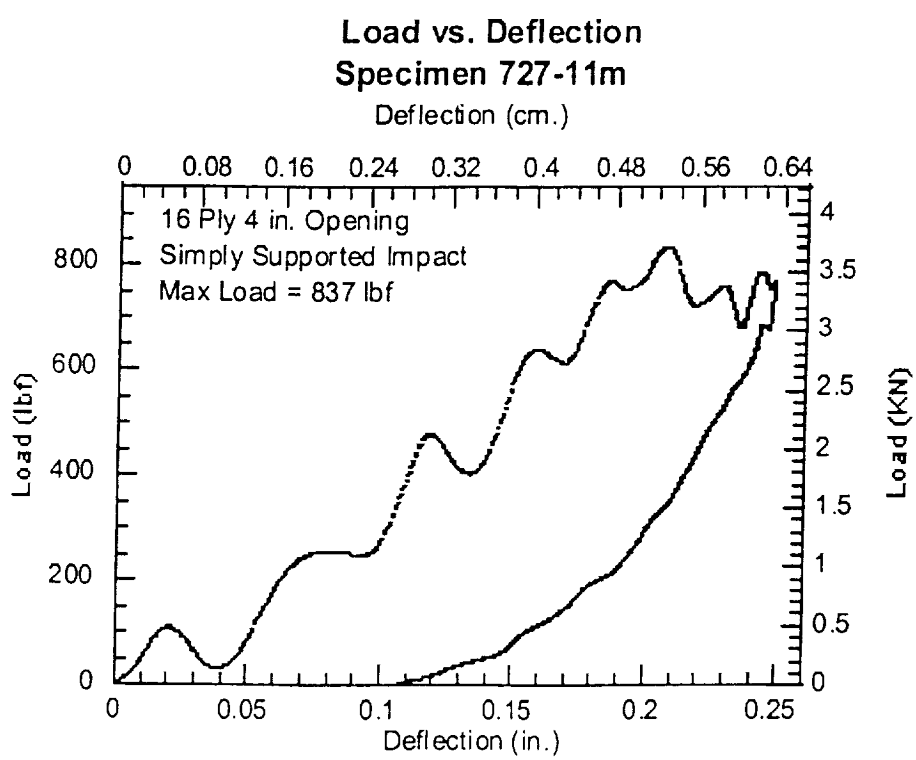


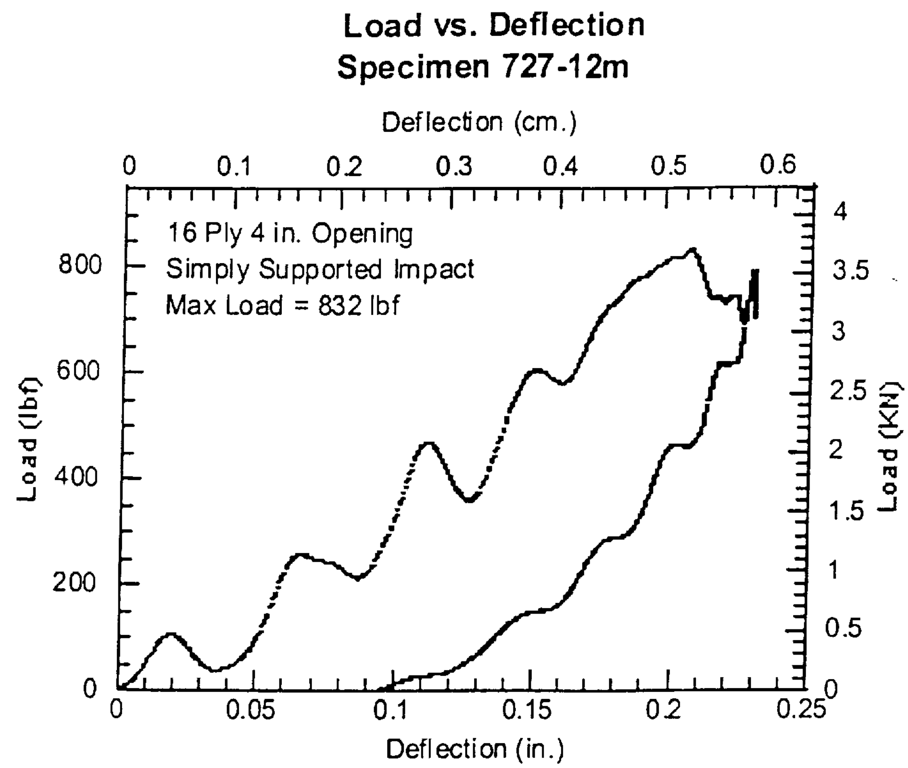
Load vs. Deflection
Specimen 728-02m
Deflection (cm.)
8 Ply 2 in. Opening
Simply Supported Impact
Max Load = 230 lbf
Load (lbf)
Load (KN)
Deflection (in.)



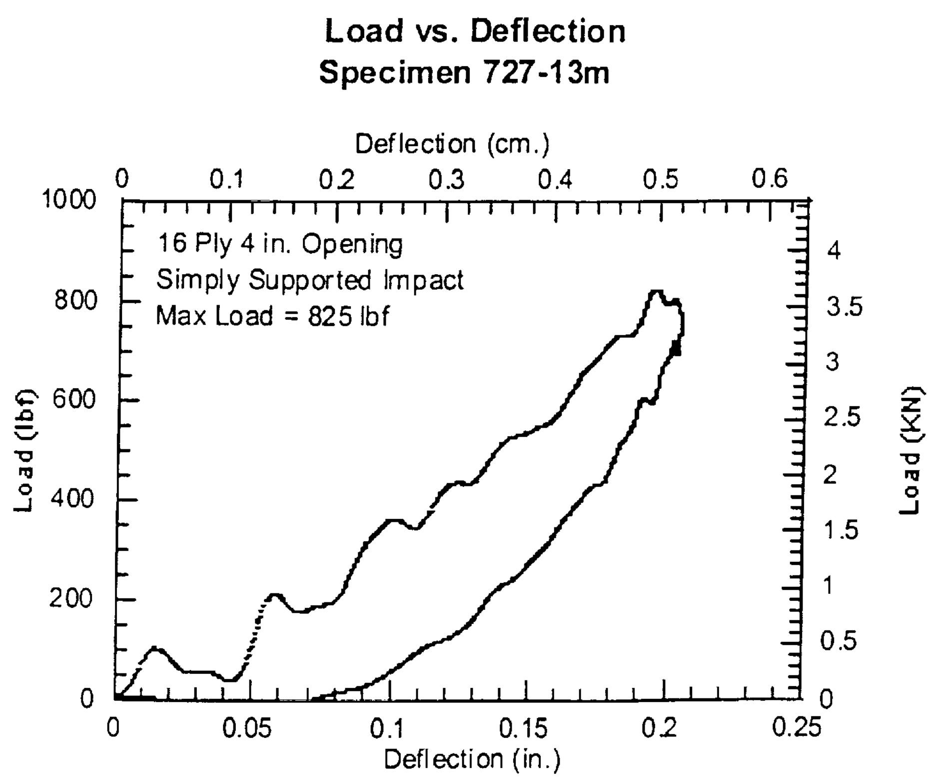
Load vs. Deflection
Specimen 728-03m
Deflection (cm.)
8 Ply 2 in. Opening
Simply Supported Impact
Max Load = 219 lbf
Load (lbf)
Load (KN)
Deflection (in.)


Load vs. Deflection
Specimen 728-04m
Deflection (cm.)
0
0.05
0.1
0.15
0.2
0.25
8 Ply 2 in. Opening
Simply Supported Impact
Max Load = 204 lbf
Load (lbf)
200
150
100
50
0
Load (KN)
1
0.8
0.6
0.4
0.2
0
0.02
0.04
0.06
0.08
0.1
Deflection (in.)

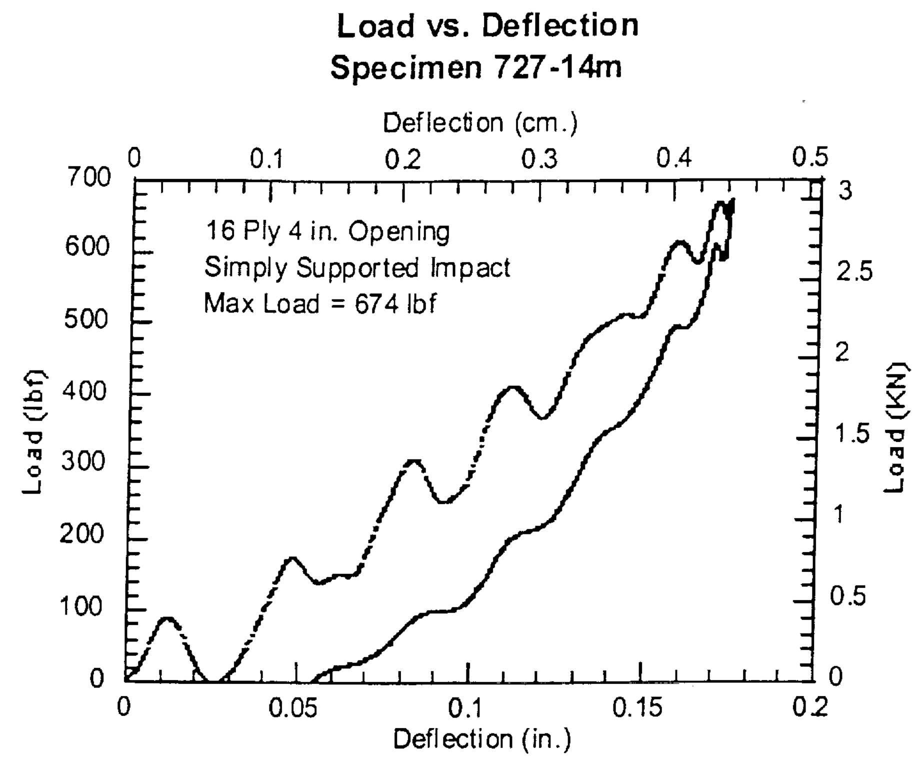

Load vs. Deflection
Specimen 727-11m
Deflection (cm.)
0
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
16 Ply 4 in. Opening
Simply Supported Impact
Max Load = 837 lbf
Load (lbf)
800
600
400
200
0
Load (KN)
4
3.5
3
2.5
2
1.5
1
0.5
0.05
0.1
0.15
0.2
0.25
Deflection (in.)

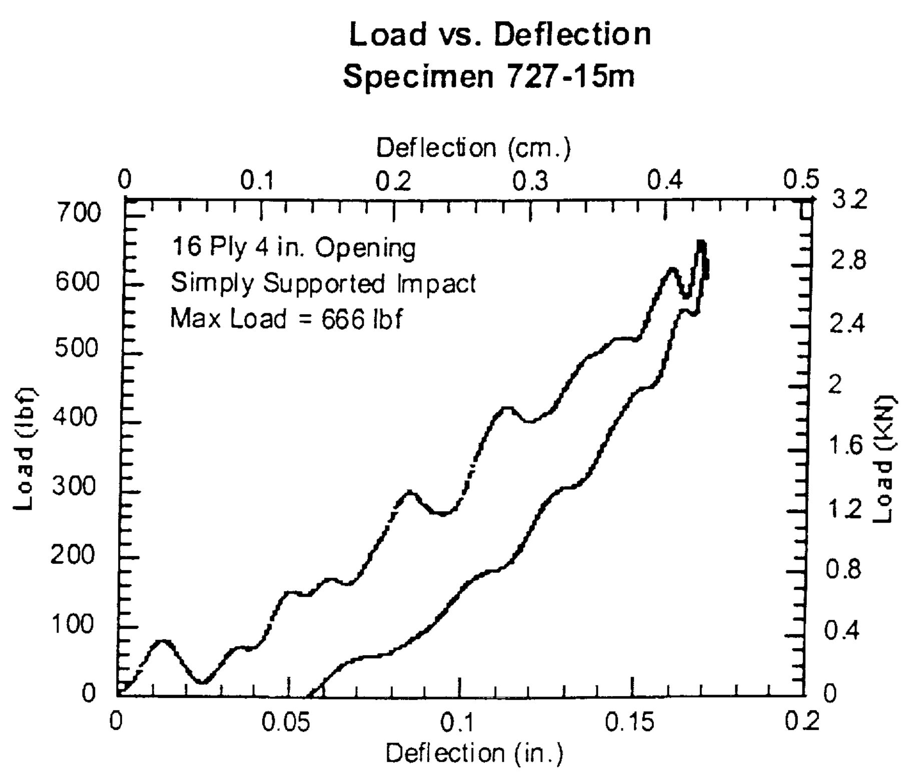


Load vs. Deflection
Specimen 727-12m
Deflection (cm.)
0
0.1
0.2
0.3
0.4
0.5
0.6
16 Ply 4 in. Opening
Simply Supported Impact
Max Load = 832 lbf
Load (lbf)
800
600
400
200
0
Load (KN)
4
3.5
3
2.5
2
1.5
1
0.5
0
0.05
0.1
0.15
0.2
0.25
Deflection (in.)

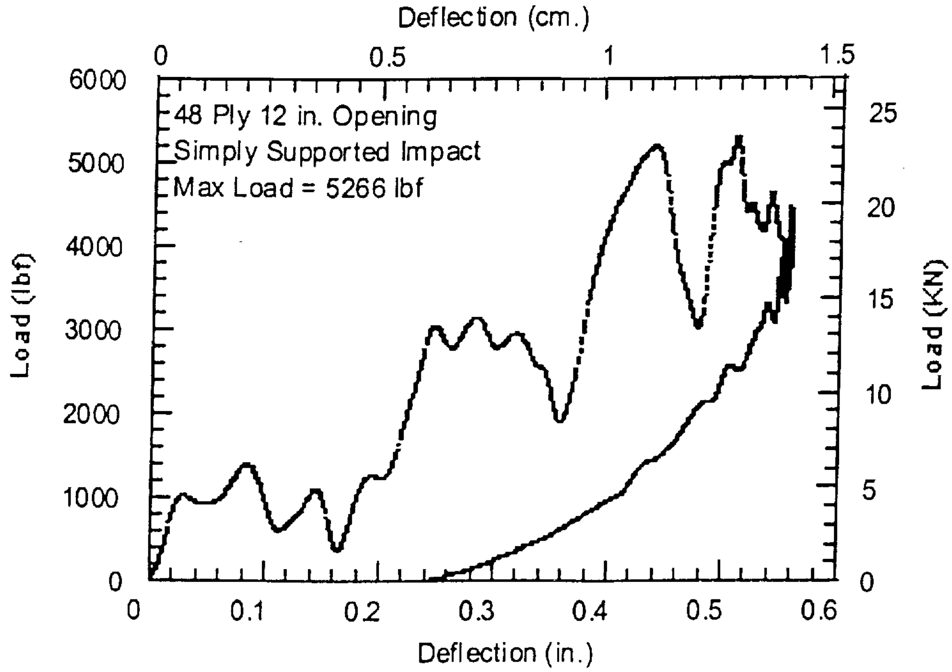


Load vs. Deflection
Specimen 727-13m
Deflection (cm.)
0
0.1
0.2
0.3
0.4
0.5
0.6
16 Ply 4 in. Opening
Simply Supported Impact
Max Load = 825 lbf
Load (lbf)
1000
800
600
400
200
0
Load (KN)
4
3.5
3
2.5
2
1.5
1
0.5
0
0.05
0.1
0.15
0.2
0.25
Deflection (in.)

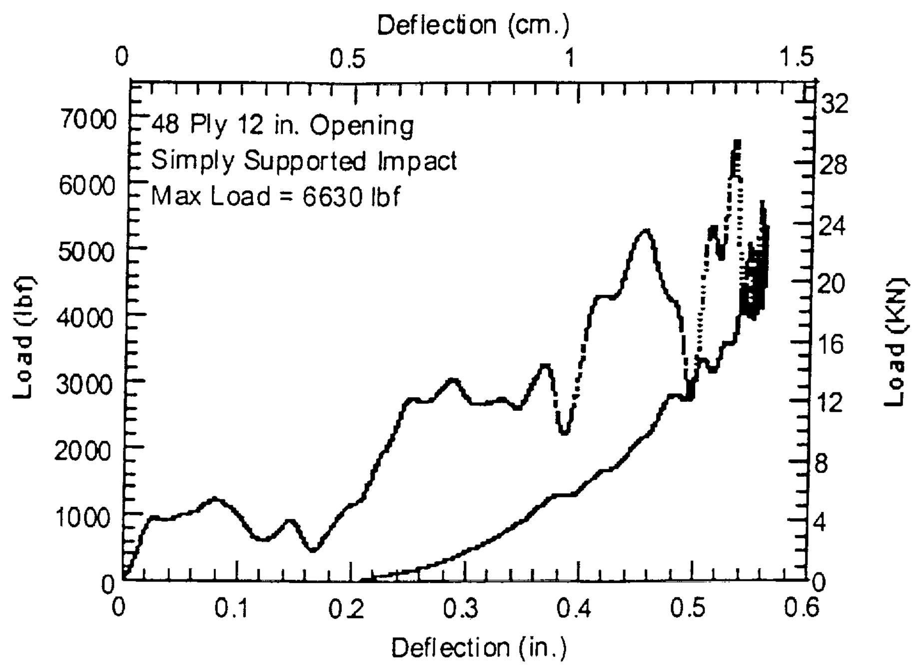

Load vs. Deflection
Specimen 727-14m
Deflection (cm.)
0
0.1
0.2
0.3
0.4
0.5
16 Ply 4 in. Opening
Simply Supported Impact
Max Load = 674 lbf
Load (lbf)
700
600
500
400
300
200
100
0
Load (KN)
3
2.5
2
1.5
1
0.5
0
0.05
0.1
0.15
0.2
Deflection (in.)


Load vs. Deflection
Specimen 727-15m
Deflection (cm.)
0
0.1
0.2
0.3
0.4
0.5
16 Ply 4 in. Opening
Simply Supported Impact
Max Load = 666 lbf
Load (lbf)
700
600
500
400
300
200
100
0
Load (KN)
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
0.05
0.1
0.15
0.2
Deflection (in.)

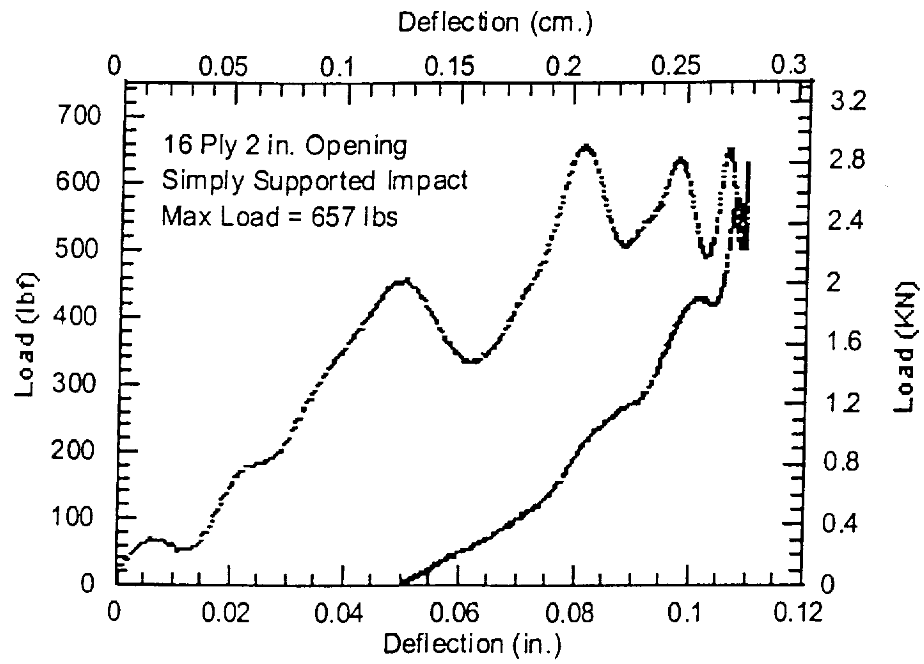
Load vs. Deflection
Specimen 61599-02m



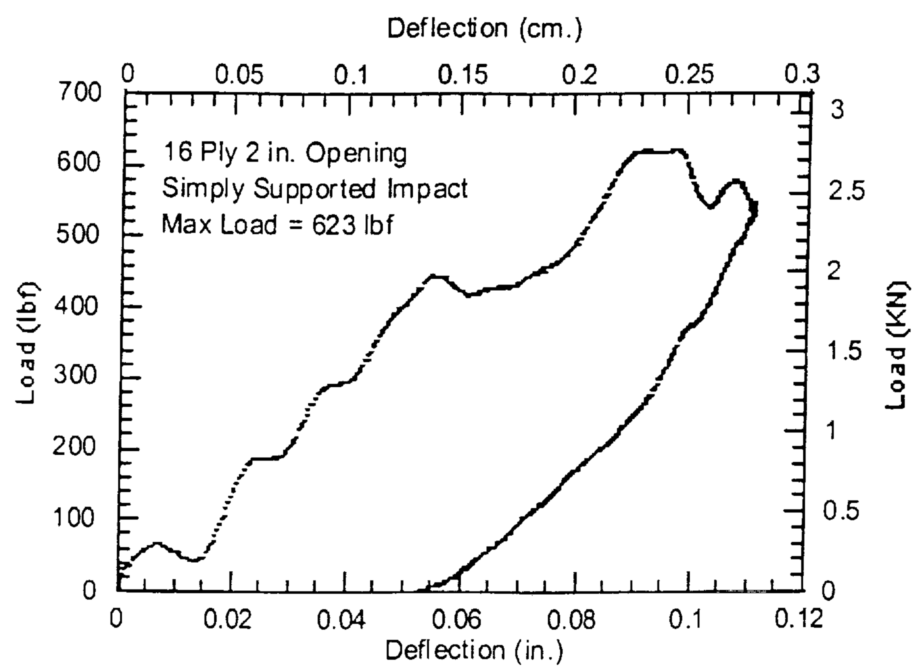
Load vs. Deflection
Specimen 61599-03



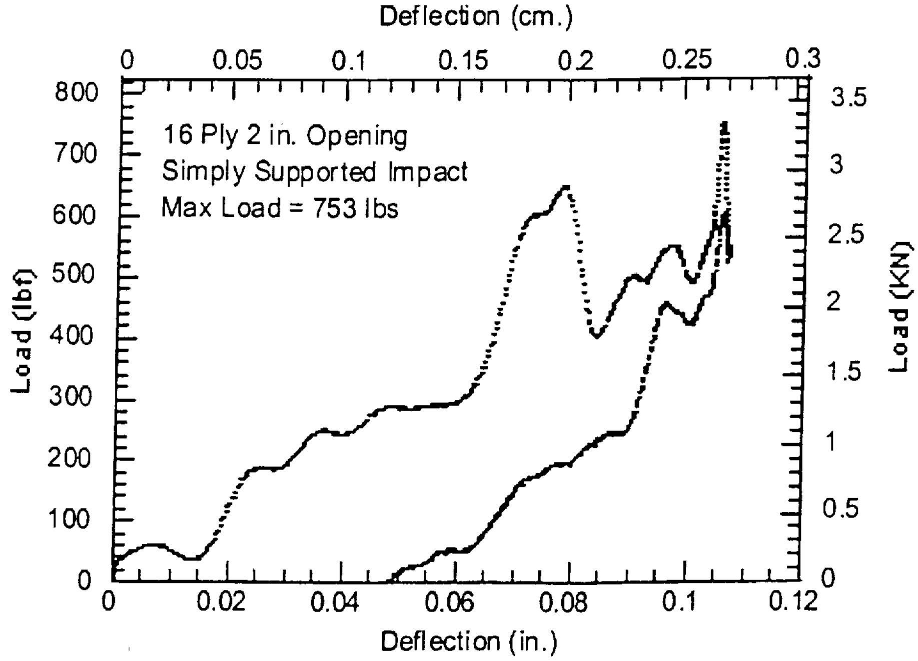
Load vs. Deflection
Specimen 727-20s



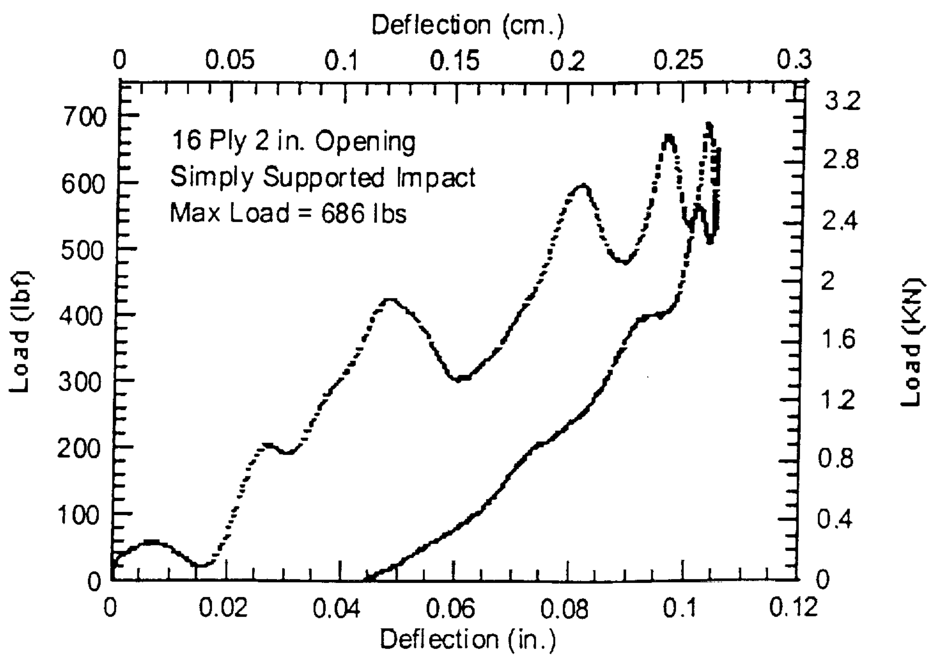
Load vs. Deflection
Specimen 727-21s

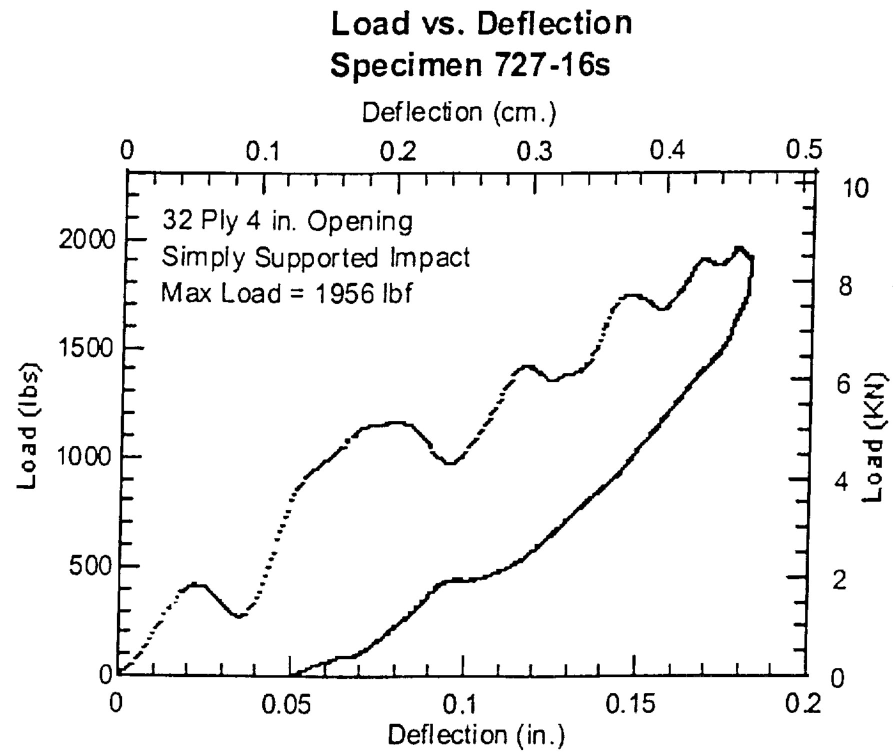


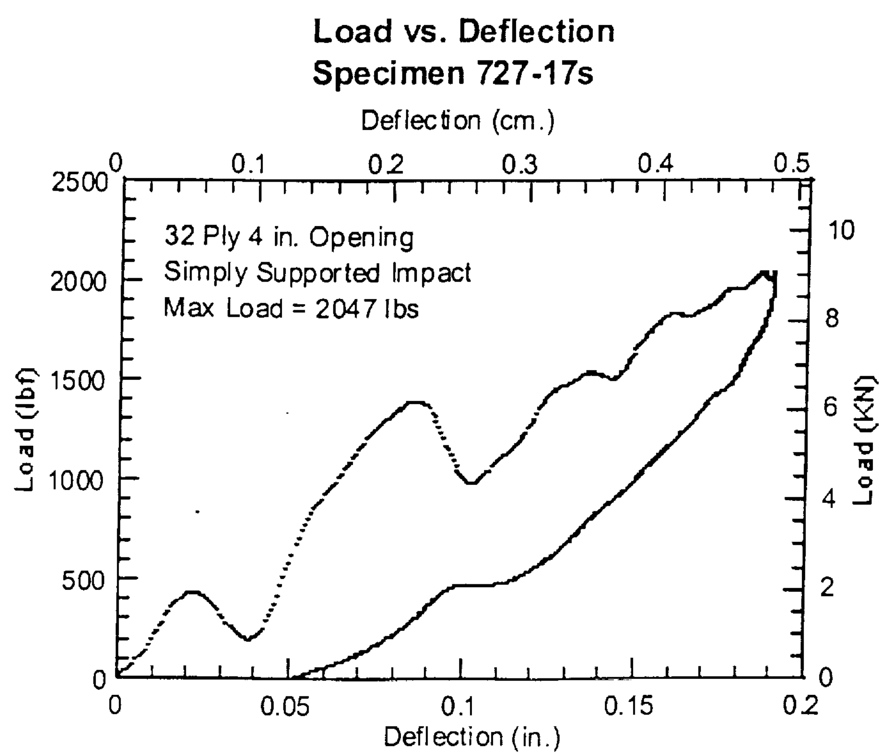
Load vs. Deflection
Specimen 727-22s

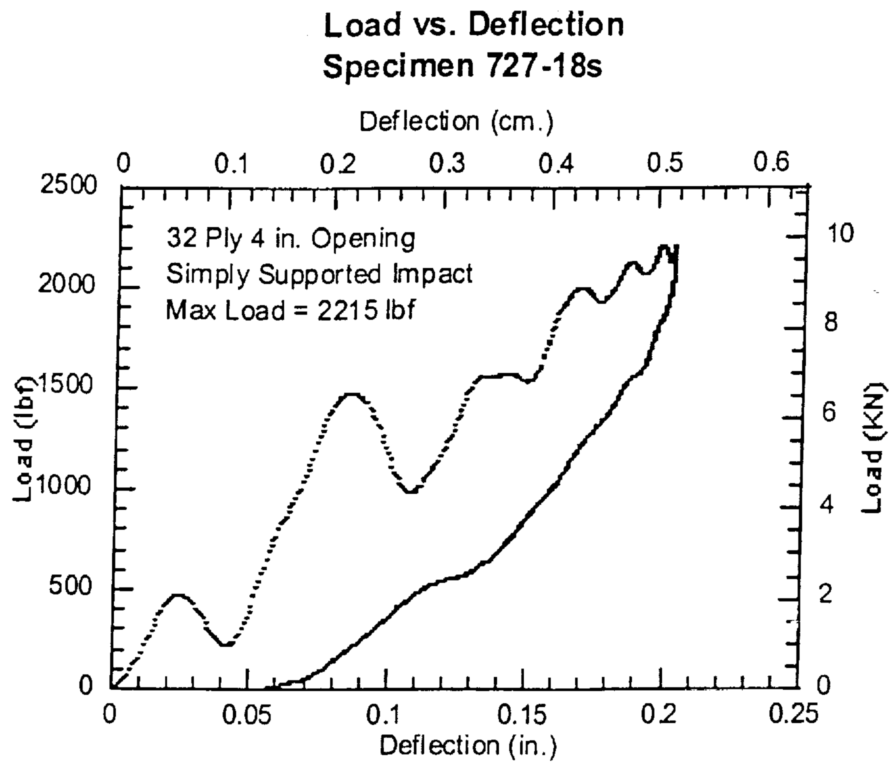


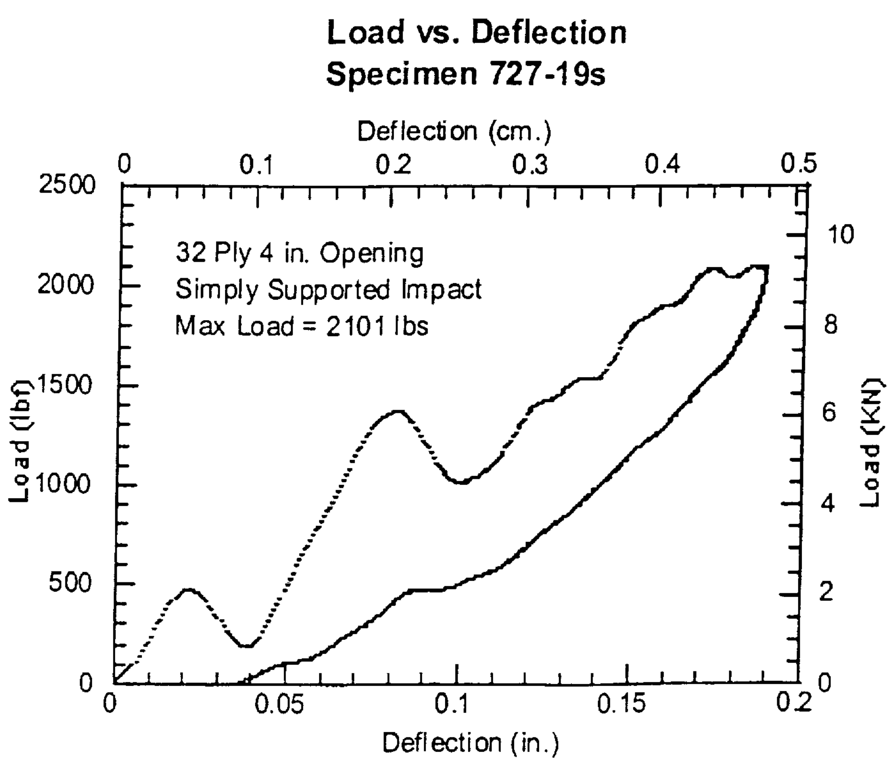
Load vs. Deflection
Specimen 728-01s



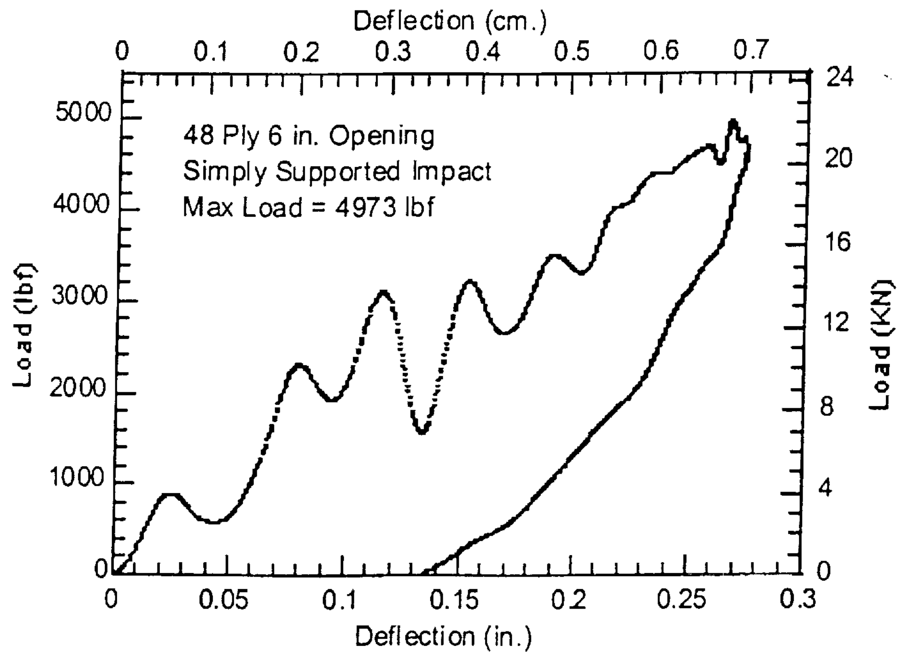

Load vs. Deflection
Specimen 727-16s
Deflection (cm.)
0
0.1
0.2
0.3
0.4
0.5
32 Ply 4 in. Opening
Simply Supported Impact
Max Load = 1956 lbf
Load (lbs)
2000
1500
1000
500
0
Load (KN)
10
8
6
4
2
0
0
0.05
0.1
0.15
0.2
Deflection (in.)

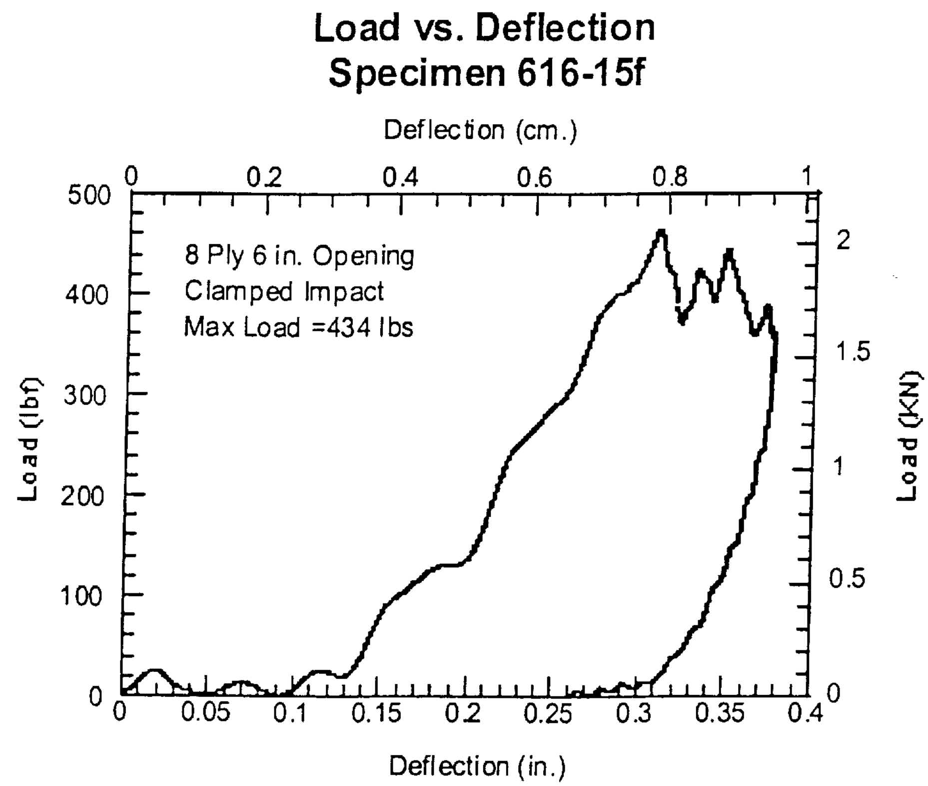

Load vs. Deflection
Specimen 727-17s
Deflection (cm.)
0
0.1
0.2
0.3
0.4
0.5
32 Ply 4 in. Opening
Simply Supported Impact
Max Load = 2047 lbs
Load (lbf)
2500
2000
1500
1000
500
0
Load (KN)
10
8
6
4
2
0
0
0.05
0.1
0.15
0.2
Deflection (in.)


Load vs. Deflection
Specimen 727-18s
Deflection (cm.)
32 Ply 4 in. Opening
Simply Supported Impact
Max Load = 2215 lbf
Load (lbf)
Load (KN)
Deflection (in.)

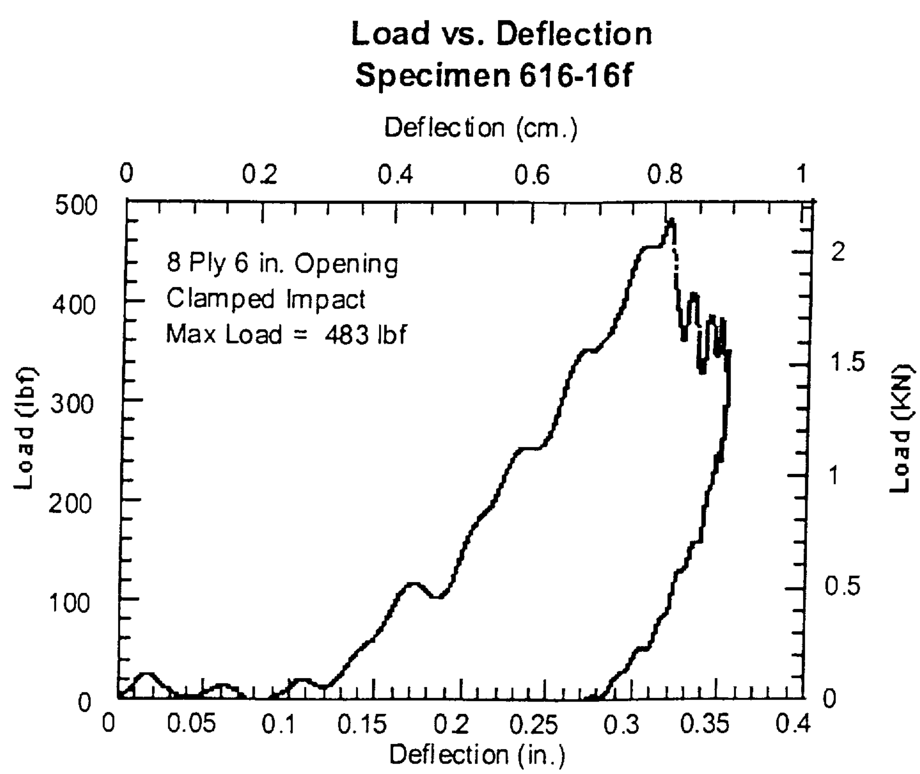

Load vs. Deflection
Specimen 727-19s
Deflection (cm.)
32 Ply 4 in. Opening
Simply Supported Impact
Max Load = 2101 lbs
Load (lbf)
Load (KN)
Deflection (in.)

Load vs. Deflection
Specimen 727-02s

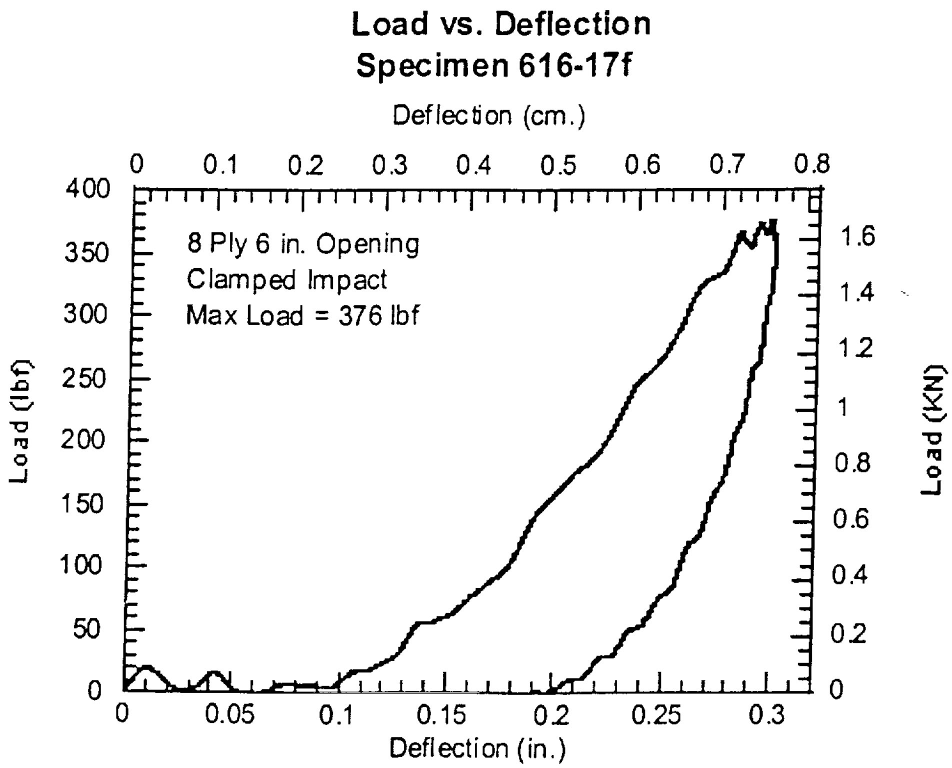


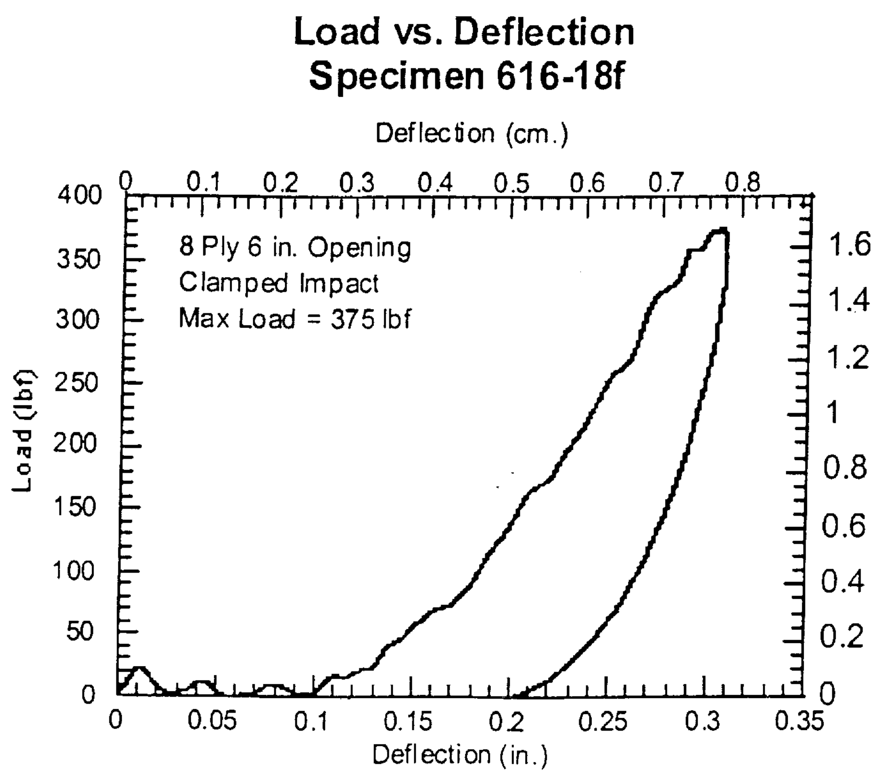


Load vs. Deflection
Specimen 616-15f
Deflection (cm.)
0
0.2
0.4
0.6
0.8
1
500
400
300
200
100
0
2
1.5
1
0.5
0
8 Ply 6 in. Opening
Clamped Impact
Max Load =434 lbs
Load (lbf)
Load (KN)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Deflection (in.)

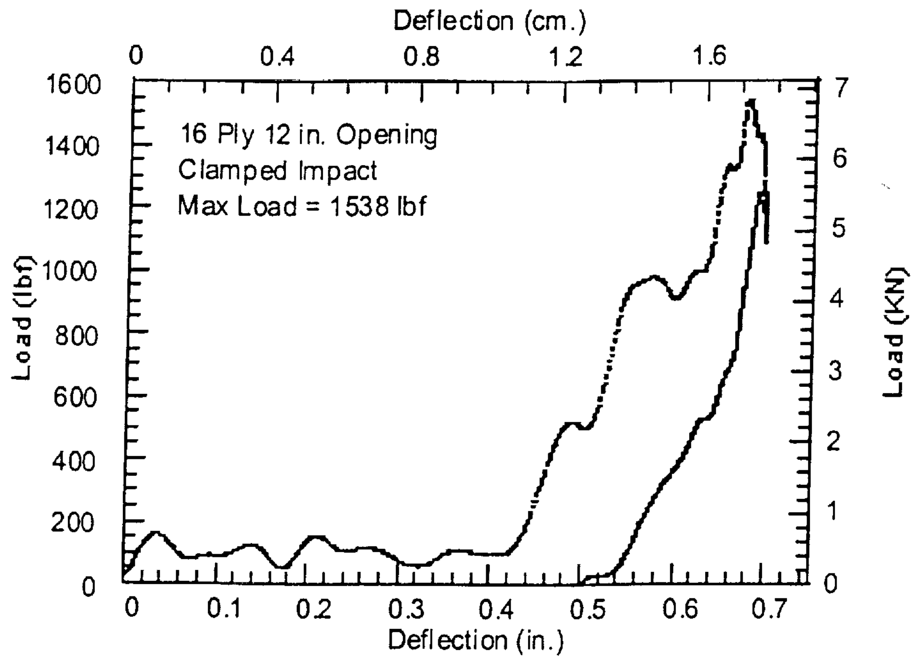


Load vs. Deflection
Specimen 616-16f
Deflection (cm.)
0
0.2
0.4
0.6
0.8
1
500
400
300
200
100
0
2
1.5
1
0.5
0
8 Ply 6 in. Opening
Clamped Impact
Max Load = 483 lbf
Load (lbf)
Load (KN)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Deflection (in.)

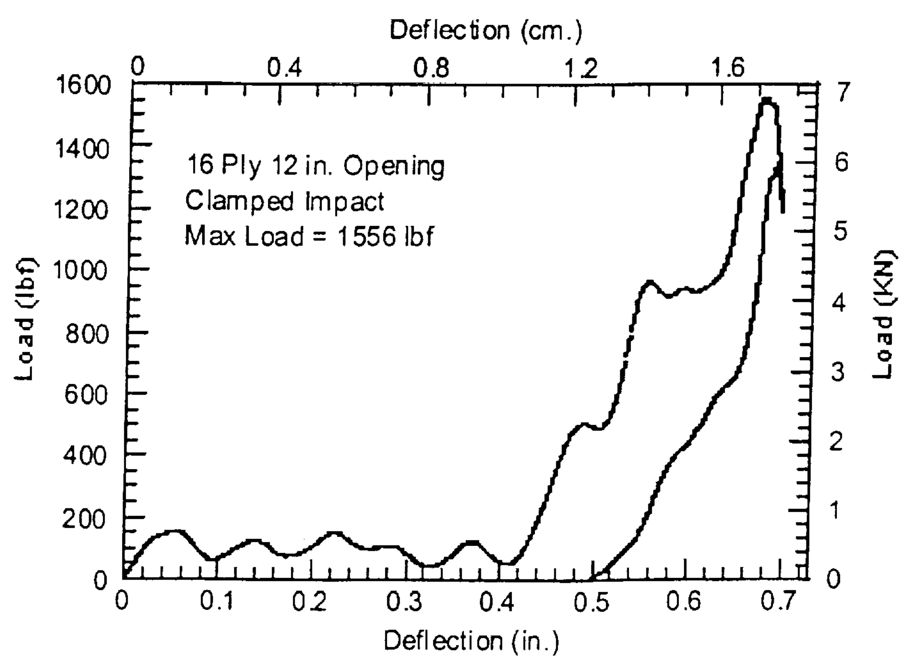

Load vs. Deflection
Specimen 616-17f
Deflection (cm.)
Load (lbf)
Load (KN)
Deflection (in.)
8 Ply 6 in. Opening
Clamped Impact
Max Load = 376 lbf


Load vs. Deflection
Specimen 616-18f
Deflection (cm.)
Load (lbf)
Load (KN)
Deflection (in.)
8 Ply 6 in. Opening
Clamped Impact
Max Load = 375 lbf

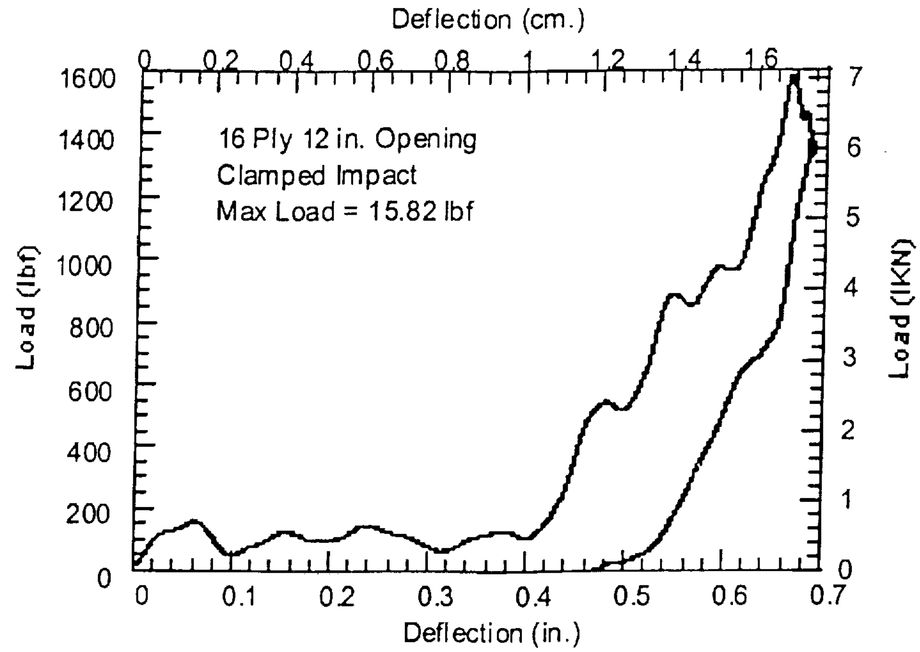
Load vs. Deflection
Specimen 616-01f



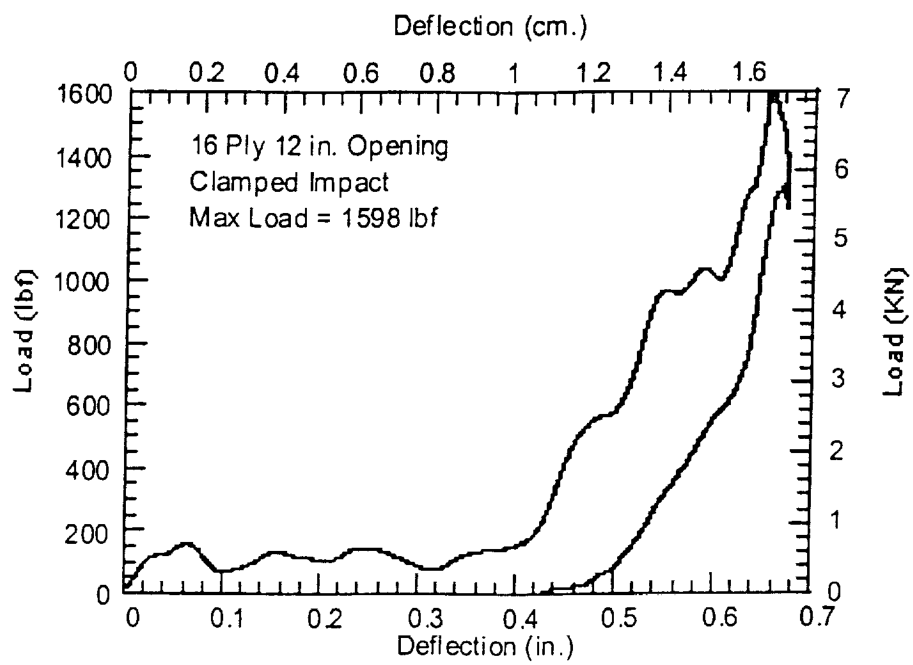
Load vs. Deflection
Specimen 616-02f



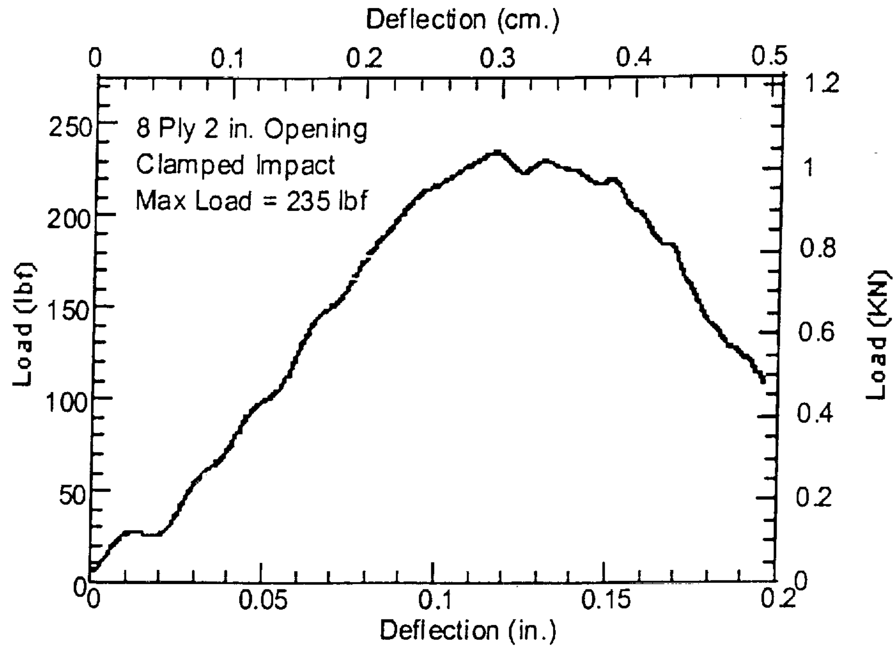
Load vs. Deflection
Specimen 616-03f



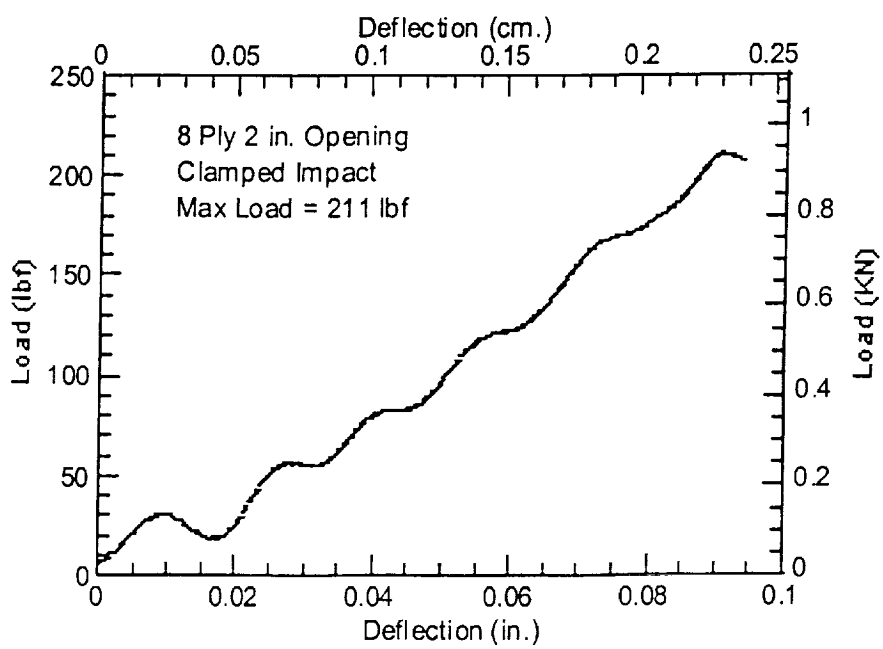
Load vs. Deflection
Specimen 616-04f



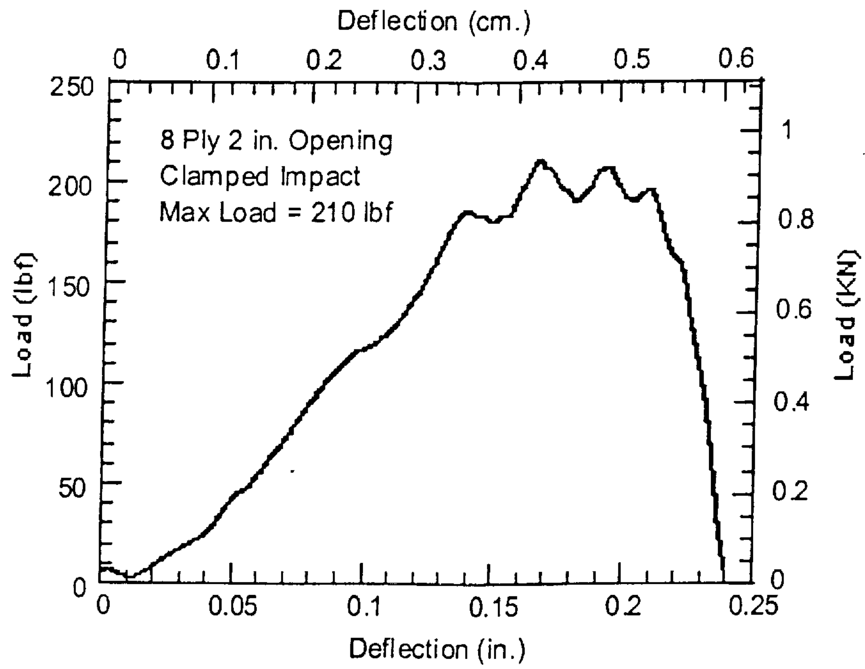
Load vs. Deflection
Specimen 616-37m



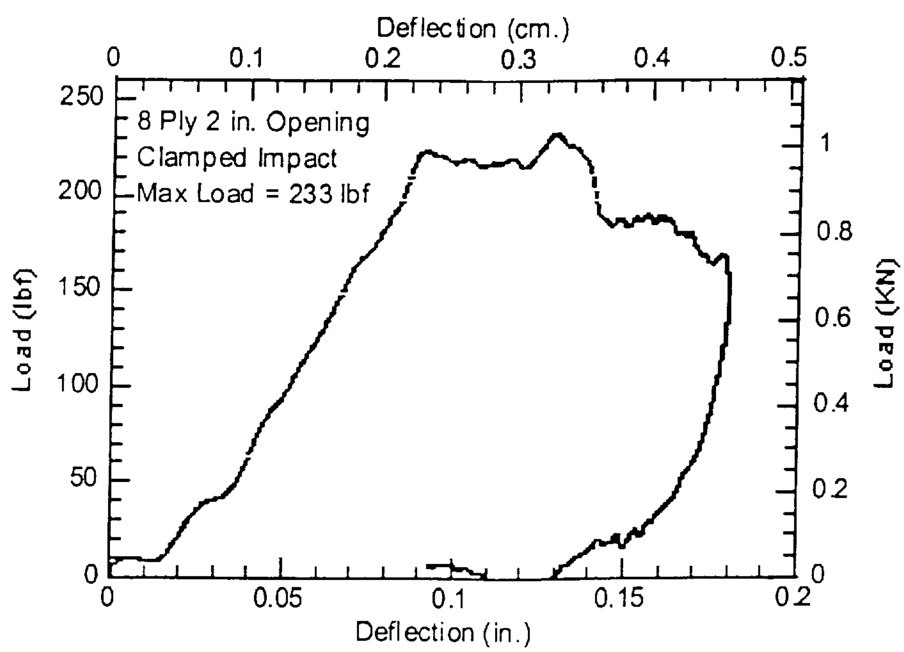
Load vs. Deflection
Specimen 616-38m

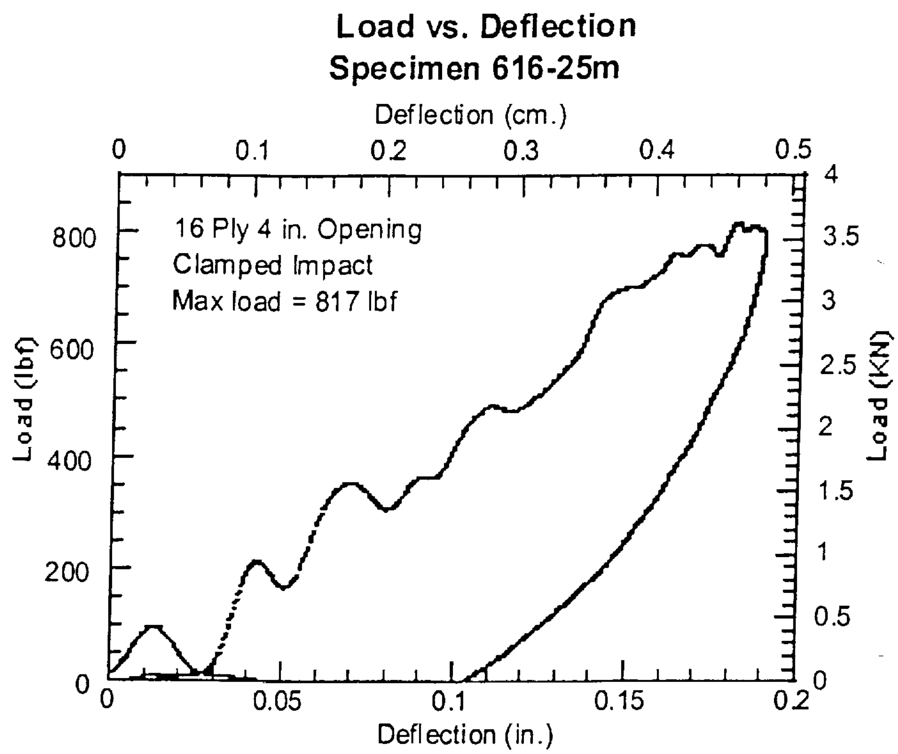


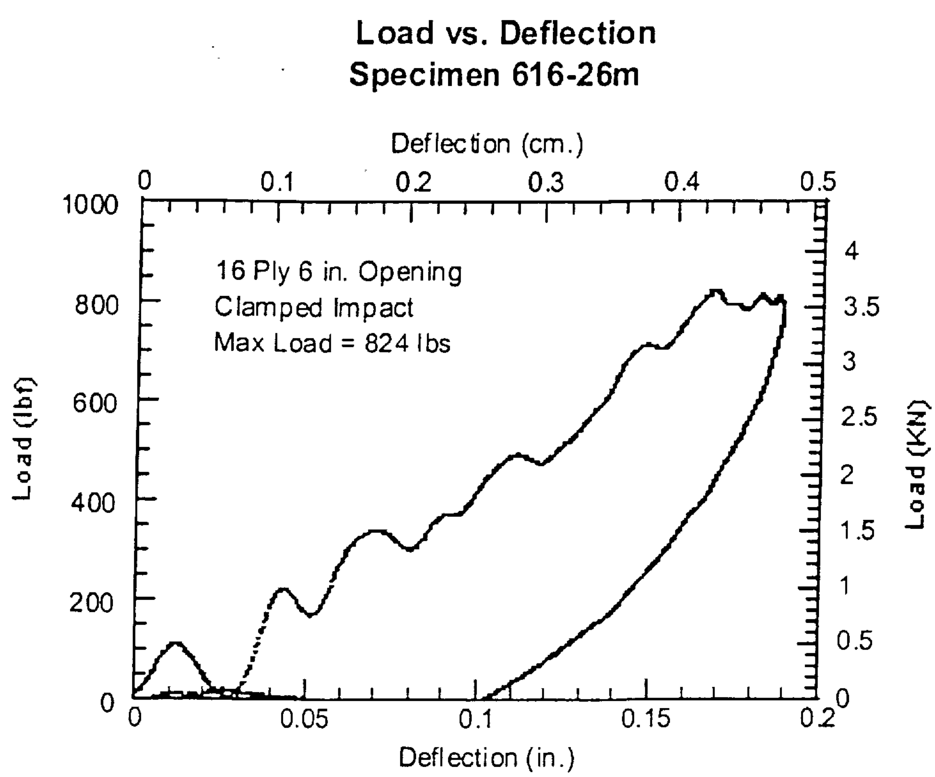
Load vs. Deflection
Specimen 728-09m



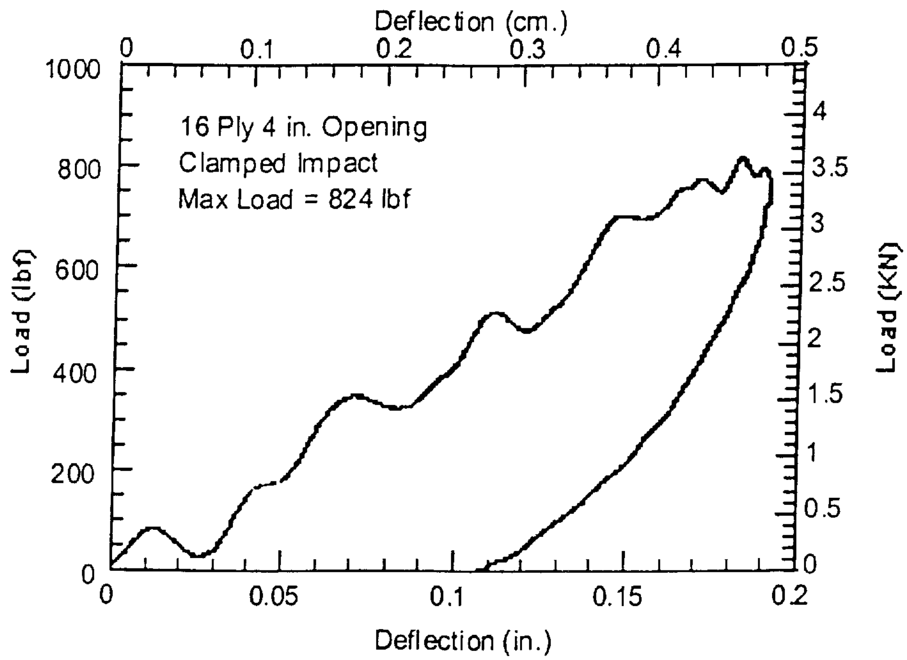
Load vs. Deflection
Specimen 728-11m



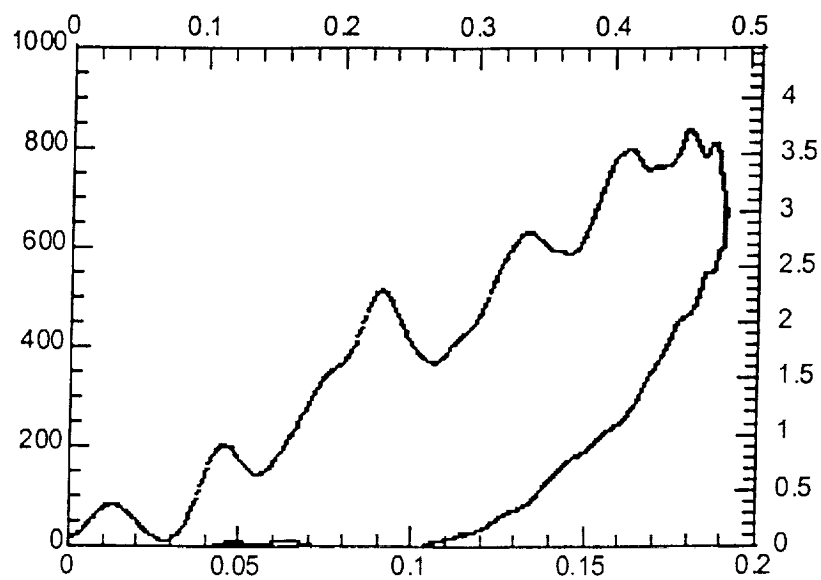

Load vs. Deflection
Specimen 616-25m
Deflection (cm.)
16 Ply 4 in. Opening
Clamped Impact
Max load = 817 lbf
Load (lbf)
Load (KN)
Deflection (in.)

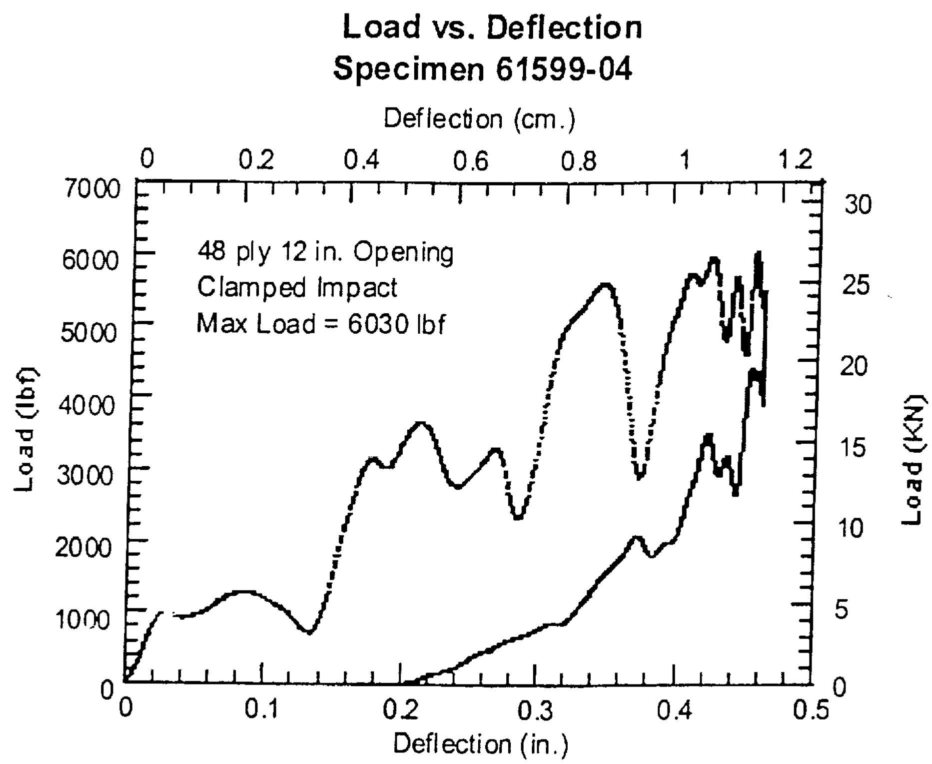

Load vs. Deflection
Specimen 616-26m
Deflection (cm.)
16 Ply 6 in. Opening
Clamped Impact
Max Load = 824 lbs
Load (lbf)
Load (KN)
Deflection (in.)

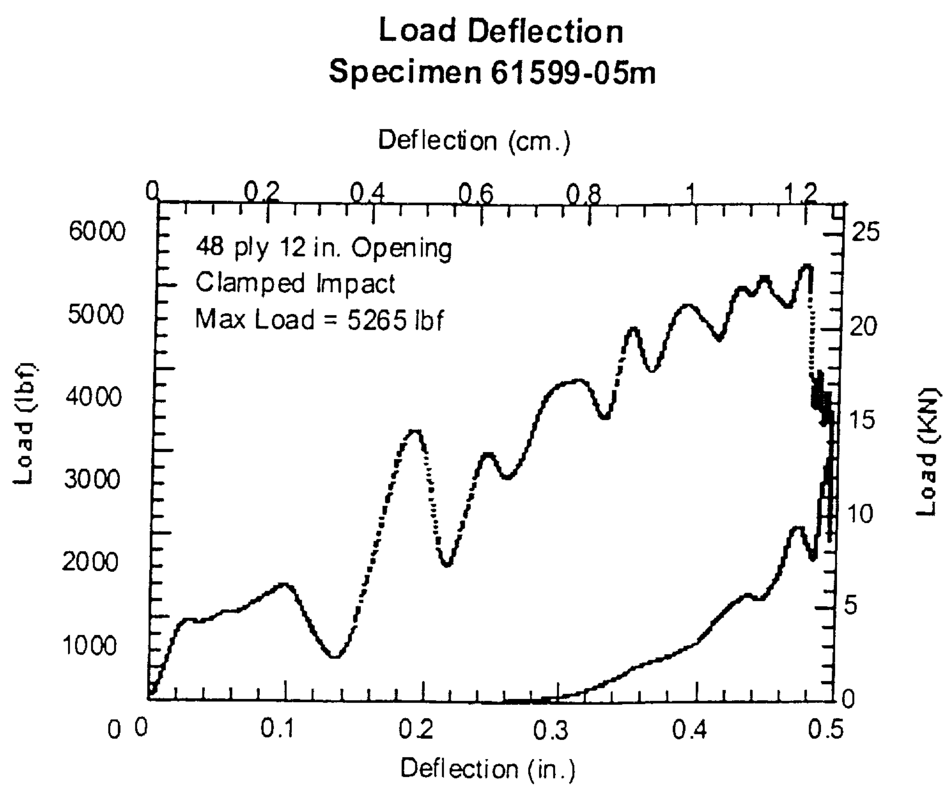
Load vs. Deflection
Specimen 616-27m

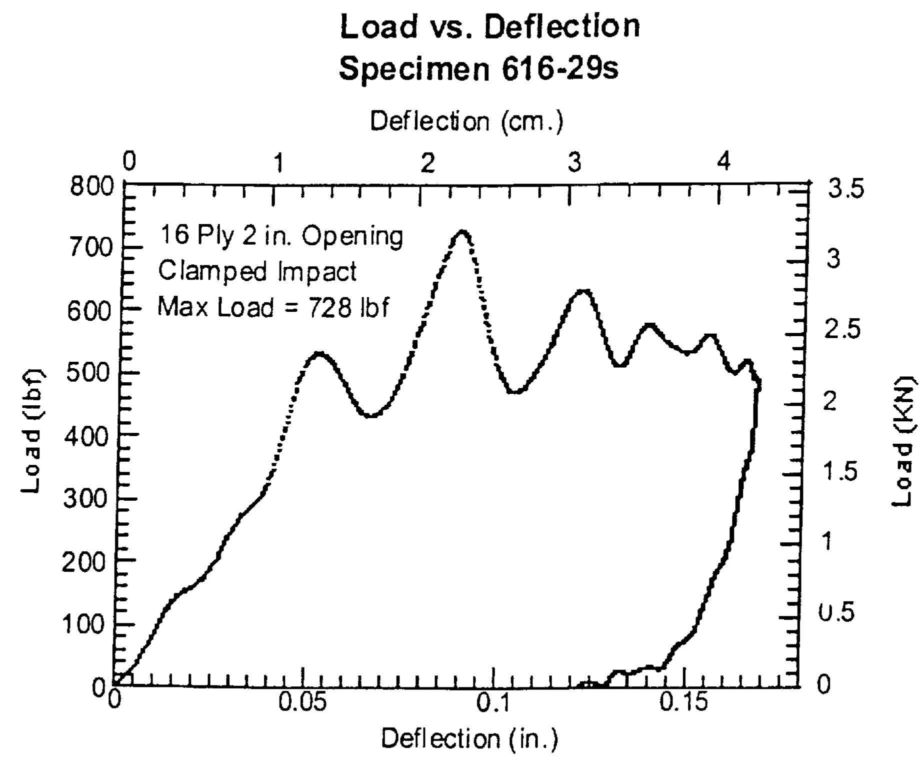


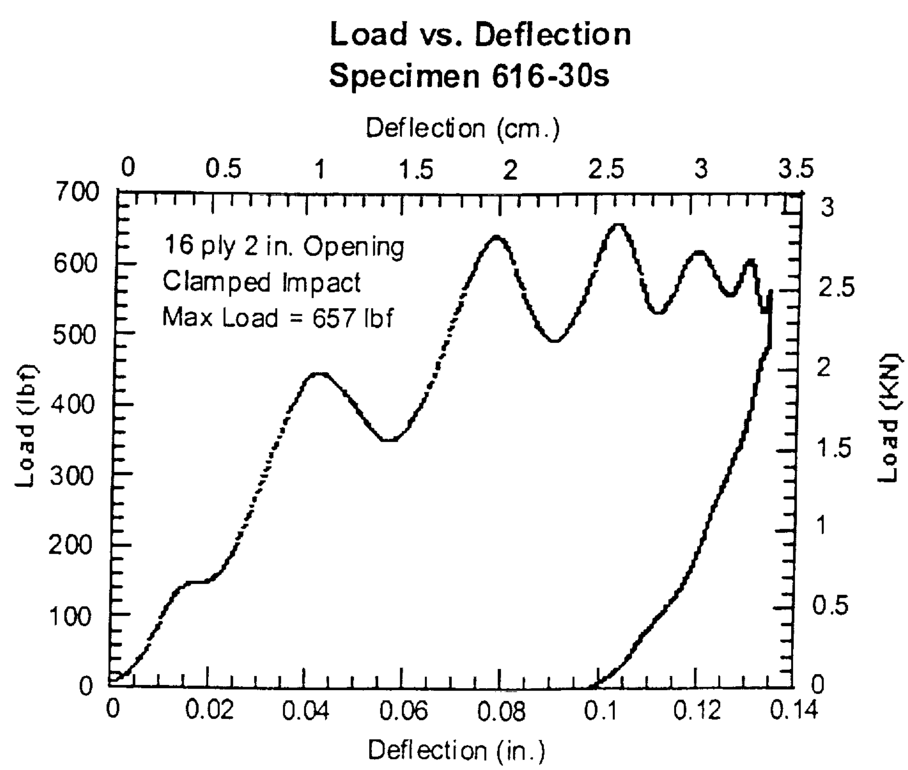
Load vs. Deflection
Specimen 616-28m

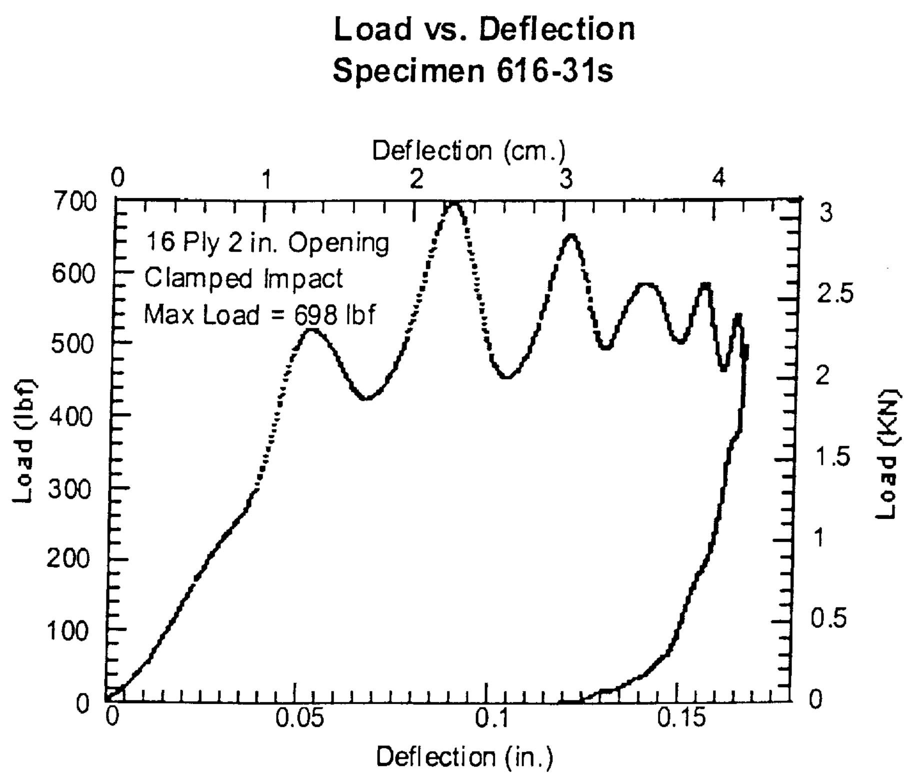


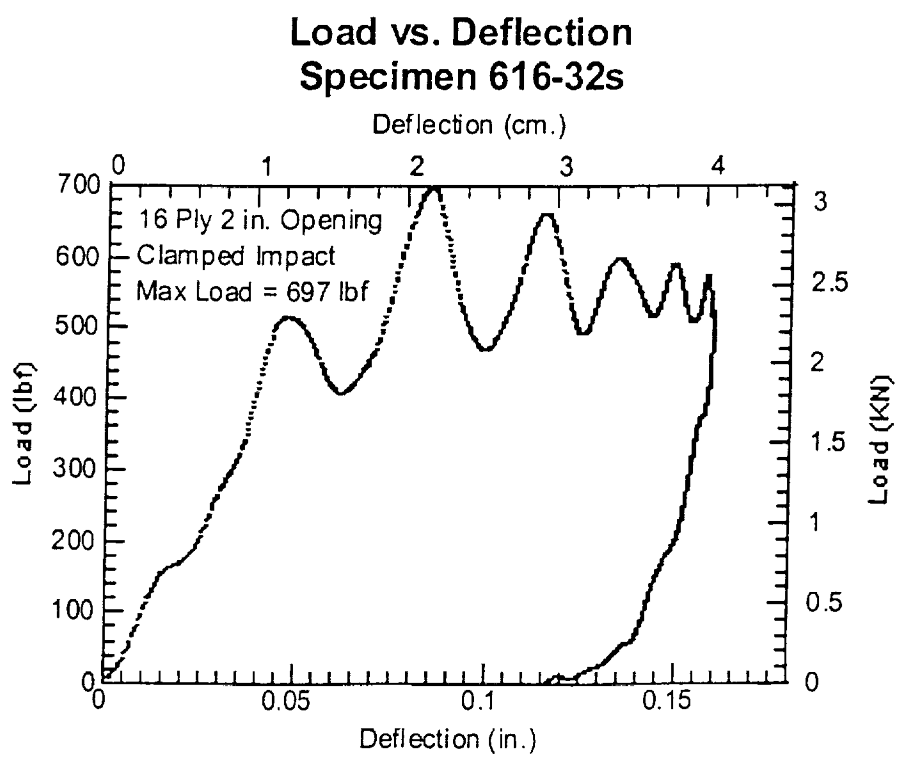

Load vs. Deflection
Specimen 61599-04
Deflection (cm.)
0
0.2
0.4
0.6
0.8
1
1.2
48 ply 12 in. Opening
Clamped Impact
Max Load = 6030 lbf
Load (lbf)
7000
6000
5000
4000
3000
2000
1000
0
30
25
20
15
10
5
0
Load (KN)
0
0.1
0.2
0.3
0.4
0.5
Deflection (in.)


Load Deflection
Specimen 61599-05m
Deflection (cm.)
0
0.2
0.4
0.6
0.8
1
1.2
48 ply 12 in. Opening
Clamped Impact
Max Load = 5265 lbf
Load (lbf)
6000
5000
4000
3000
2000
1000
0
25
20
15
10
5
0
Load (KN)
0
0.1
0.2
0.3
0.4
0.5
Deflection (in.)

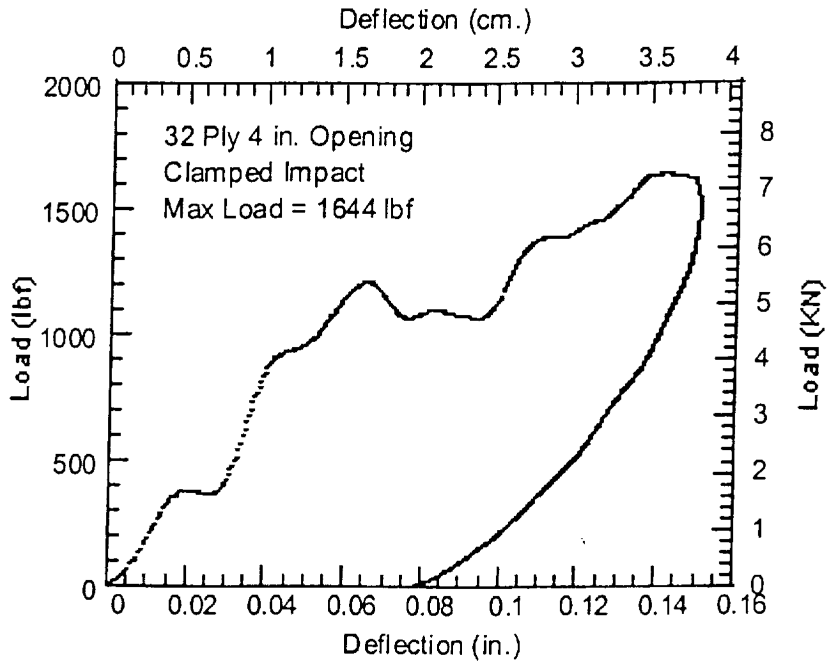

Load vs. Deflection
Specimen 616-29s
Deflection (cm.)
0
1
2
3
4
800
700
600
500
400
300
200
100
0
3.5
3
2.5
2
1.5
1
0.5
0
16 Ply 2 in. Opening
Clamped Impact
Max Load = 728 lbf
Load (lbf)
Load (KN)
0
0.05
0.1
0.15
Deflection (in.)


Load vs. Deflection
Specimen 616-30s
Deflection (cm.)
0
0.5
1
1.5
2
2.5
3
3.5
700
600
500
400
300
200
100
0
3
2.5
2
1.5
1
0.5
0
16 ply 2 in. Opening
Clamped Impact
Max Load = 657 lbf
Load (lbf)
Load (KN)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deflection (in.)

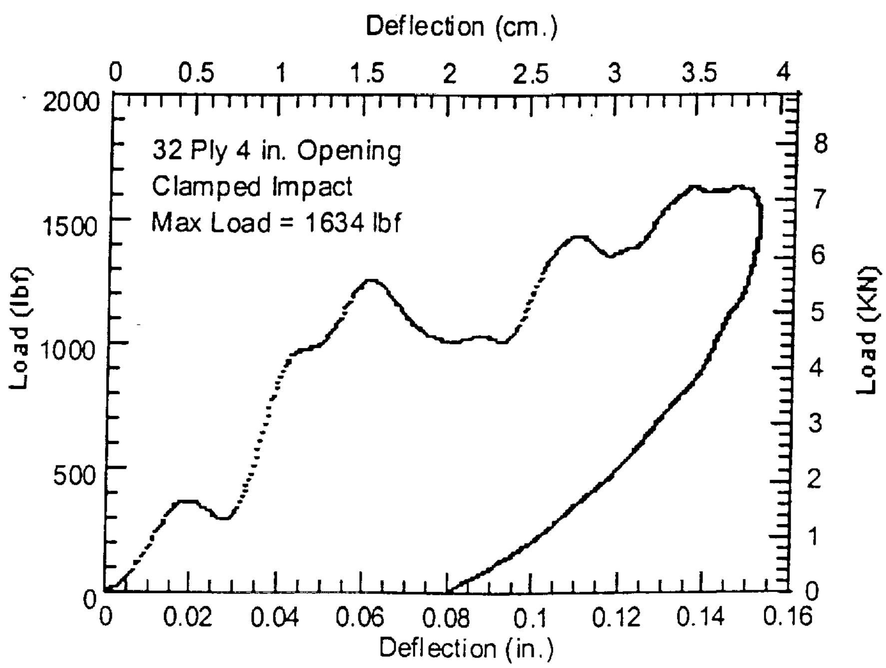

Load vs. Deflection
Specimen 616-31s
Deflection (cm.)
0
1
2
3
4
700
600
500
400
300
200
100
0
Load (lbf)
16 Ply 2 in. Opening
Clamped Impact
Max Load = 698 lbf
3
2.5
2
1.5
1
0.5
0
Load (KN)
0
0.05
0.1
0.15
Deflection (in.)

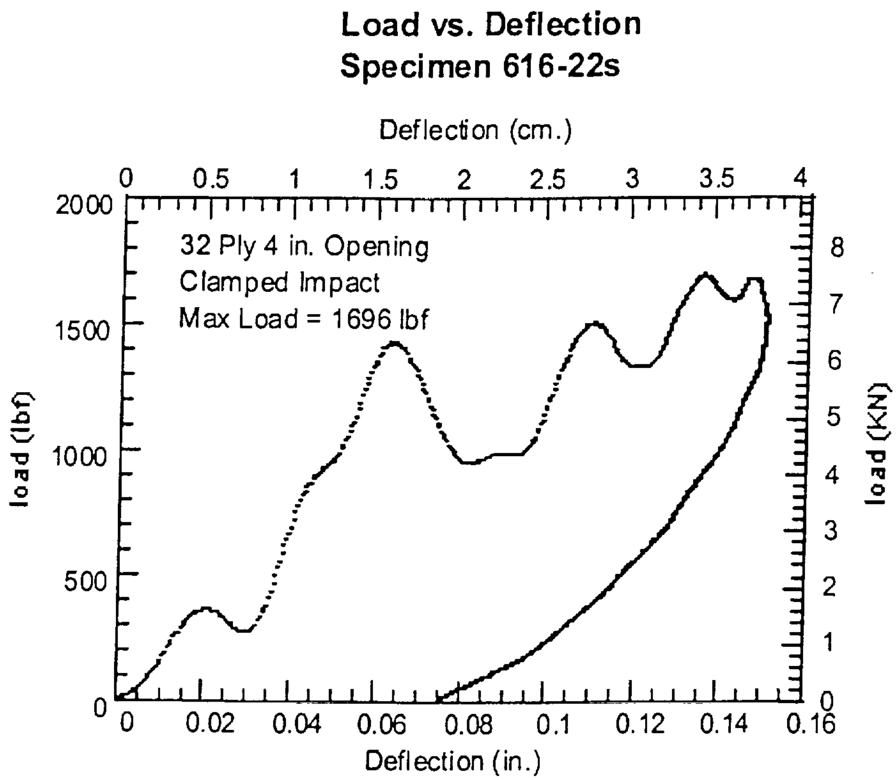

Load vs. Deflection
Specimen 616-32s
Deflection (cm.)
0
1
2
3
4
700
600
500
400
300
200
100
0
Load (lbf)
16 Ply 2 in. Opening
Clamped Impact
Max Load = 697 lbf
3
2.5
2
1.5
1
0.5
0
Load (KN)
0
0.05
0.1
0.15
Deflection (in.)

Load vs. Deflection
Specimen 616-20s



Load vs. Deflection
Specimen 616-21s

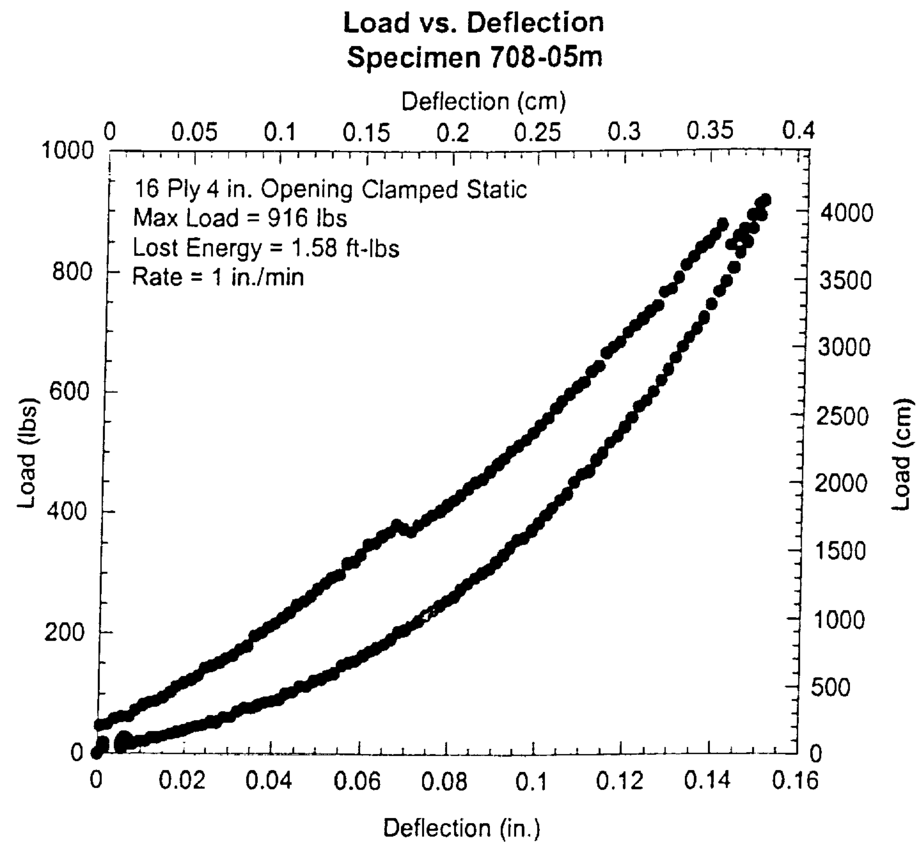




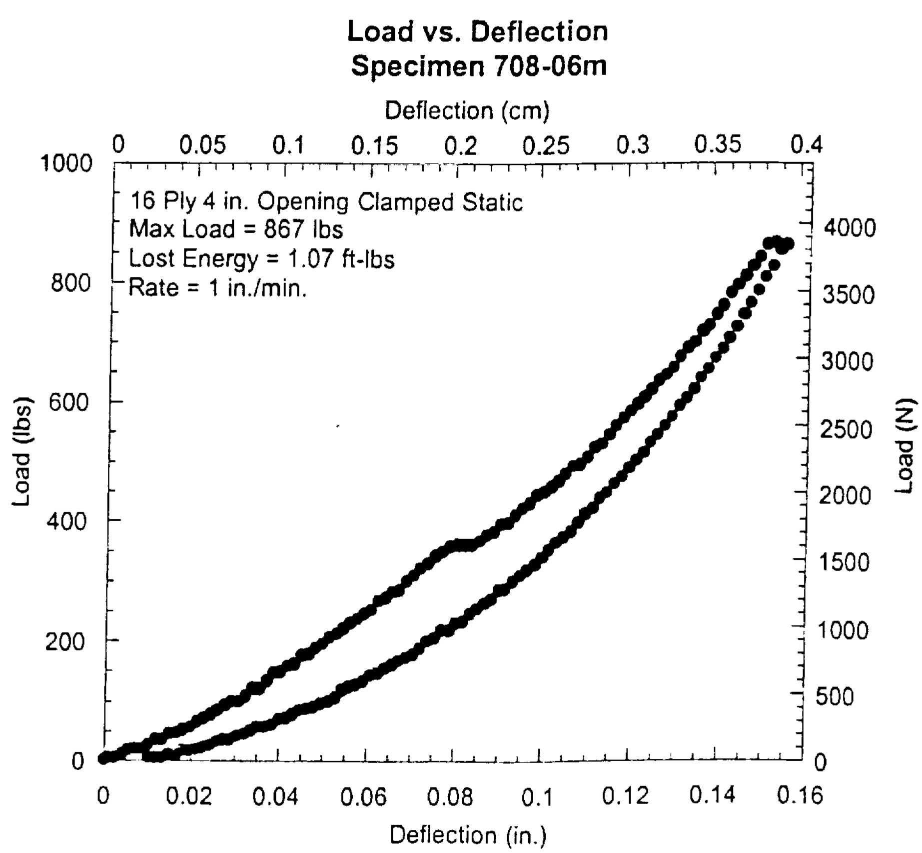
Load vs. Deflection
Specimen 616-22s
Deflection (cm.)
0
0.5
1
1.5
2
2.5
3
3.5
4
2000
1500
1000
500
0
load (lbf)
32 Ply 4 in. Opening
Clamped Impact
Max Load = 1696 lbf
8
7
6
5
4
3
2
1
0
load (KN)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
Deflection (in.)

APPENDIX C

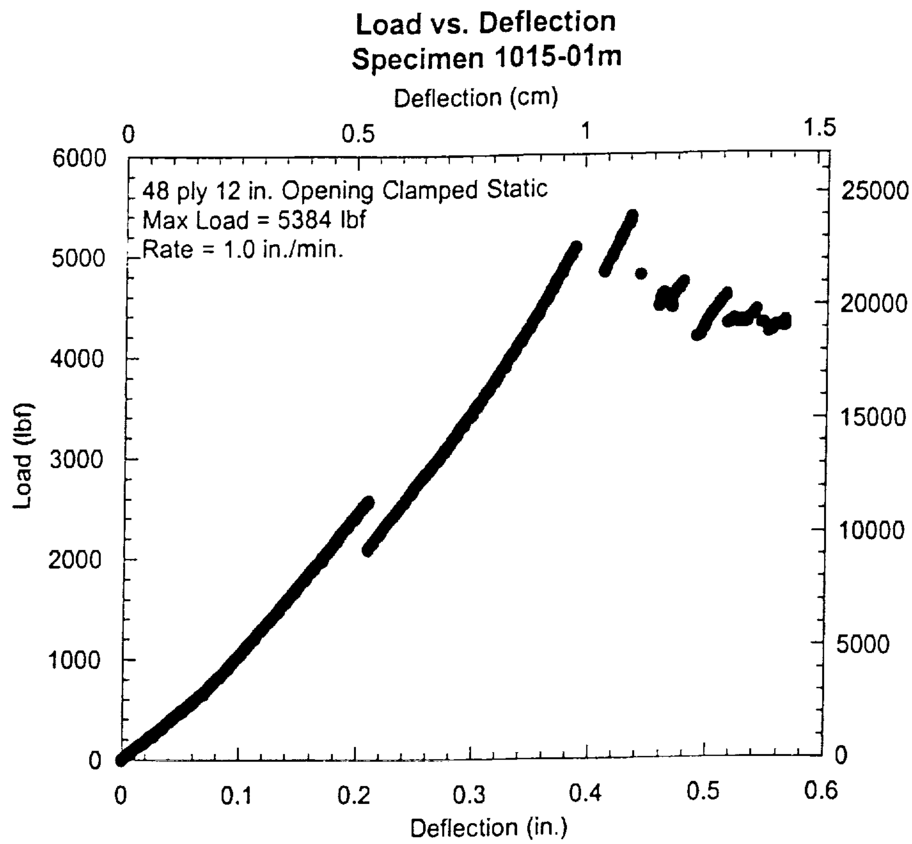
LOAD VERSUS DEFLECTION PLOTS FOR QUASI-STATIC INDENTATION TESTS



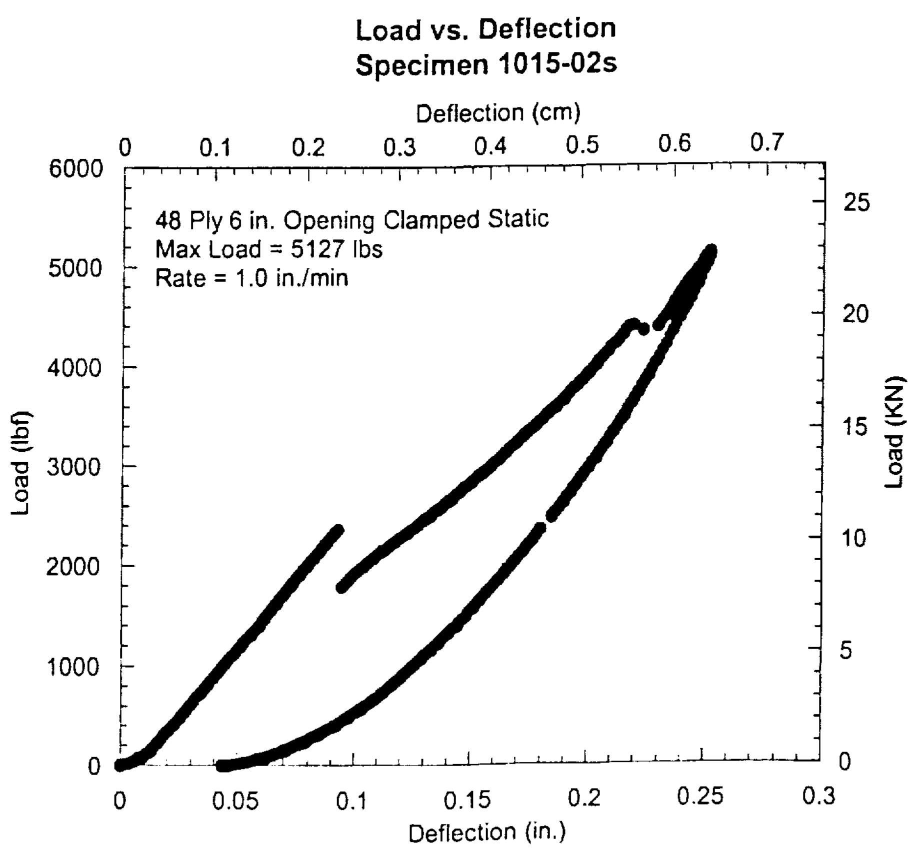
Load vs. Deflection
Specimen 708-05m
Deflection (cm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
1000
800
600
400
200
0
Load (lbs)
16 Ply 4 in. Opening Clamped Static
Max Load = 916 lbs
Lost Energy = 1.58 ft-lbs
Rate = 1 in./min
4000
3500
3000
2500
2000
1500
1000
500
0
Load (cm)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
Deflection (in.)



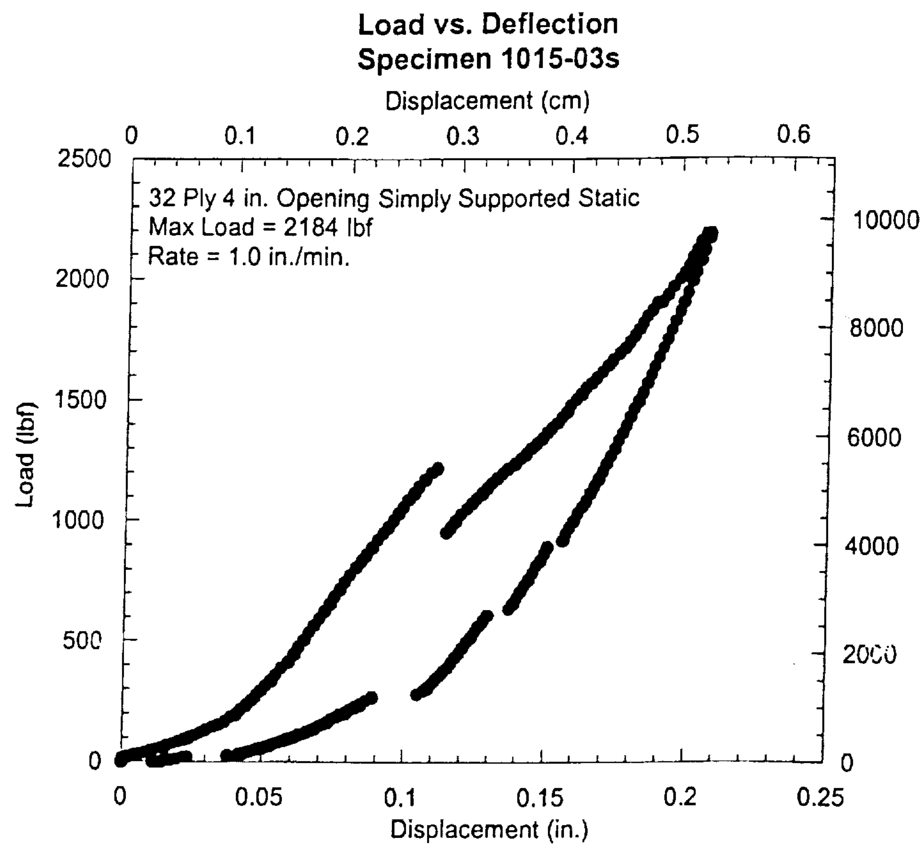
Load vs. Deflection
Specimen 708-06m
Deflection (cm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
1000
800
600
400
200
0
Load (lbs)
16 Ply 4 in. Opening Clamped Static
Max Load = 867 lbs
Lost Energy = 1.07 ft-lbs
Rate = 1 in./min.
4000
3500
3000
2500
2000
1500
1000
500
0
Load (N)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
Deflection (in.)

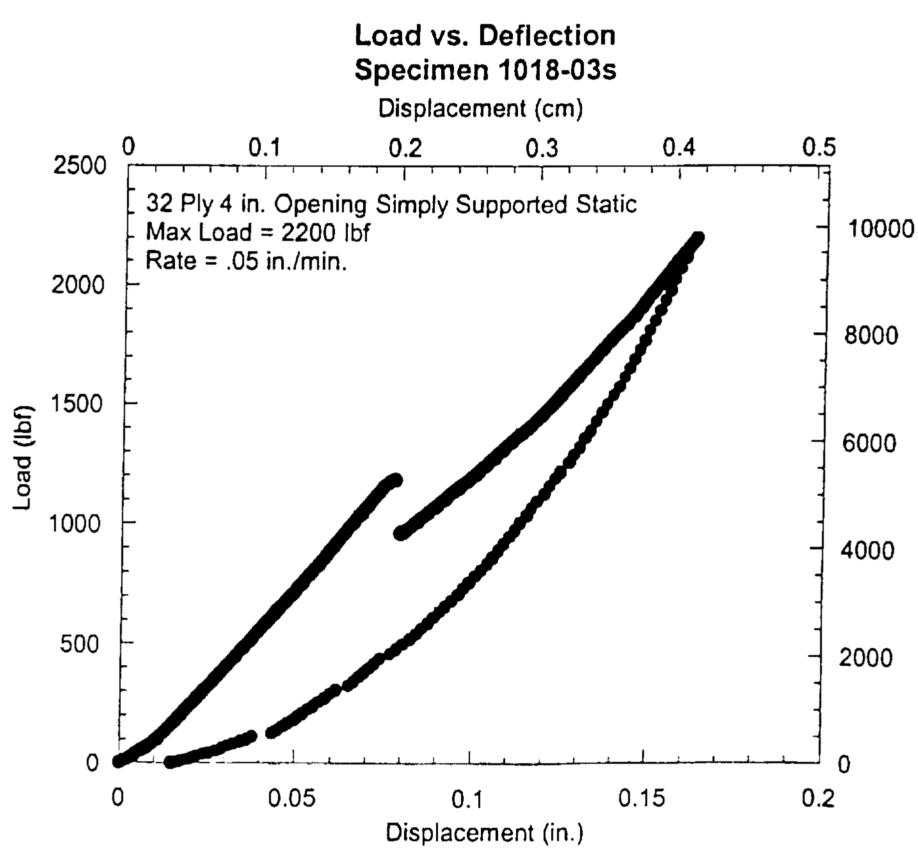


Load vs. Deflection
Specimen 1015-01m
Deflection (cm)
0
0.5
1
1.5
48 ply 12 in. Opening Clamped Static
Max Load = 5384 lbf
Rate = 1.0 in./min.
Load (lbf)
Load (N)
Deflection (in.)



Load vs. Deflection
Specimen 1015-02s
Deflection (cm)
48 Ply 6 in. Opening Clamped Static
Max Load = 5127 lbs
Rate = 1.0 in./min
Load (lbf)
Load (KN)
Deflection (in.)


Load vs. Deflection
Specimen 1015-03s
Displacement (cm)
32 Ply 4 in. Opening Simply Supported Static
Max Load = 2184 lbf
Rate = 1.0 in./min.
Load (lbf)
Load (N)
Displacement (in.)


Load vs. Deflection
Specimen 1018-03s
Displacement (cm)
32 Ply 4 in. Opening Simply Supported Static
Max Load = 2200 lbf
Rate = .05 in./min.
Load (lbf)
Load (N)
Displacement (in.)

No

Simply Supported Flex				
8 ply on 6 in. platen				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm (in)	Crack Length mm (in)	Delamination Area mm.^{2}(in.^{2})
727-06F	1850 (416)	0.102 (0.004)	16.00 (0.63)	170 (0.28)
727-07F	1766 (397)	0.075 (0.003)	47.75 (1.88)	216 (0.33)
727-08F	1850 (416)	0.075 (0.003)	22.35 (0.88)	157 (0.24)
727-09F	1873 (421)	0.075 (0.003)	25.4 (1.00)	223 (0.34)
727-10F	1873 (421)	not measurable	31.75 (1.25)	190 (0.29)
Quasi Static				
817-10F	1819 (409)	0.102 (0.004)	0.075 (0.003)	177 (0.27)
817-11F	1859 (418)	0.102 (0.004)	not measurable	111 (0.17)
817-04F	1859 (418)	0.075 (0.003)	19.05 (0.75)	190 (0.29)
817-05F	1850 (416)	0.075 (0.003)	22.35 (0.88)	190 (0.29)

16 ply on 12 in. platen				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
728-05F	4862 (1093)	0.102 (0.004)	not measurable	426 (0.65)
728-06F	5400 (1214)	0.102 (0.004)	31.75 (1.25)	499 (0.76)
728-07F	5373 (1208)	0.051 (0.002)	35.05 (1.38)	590 (0.90)
Quasi Static				
818-05F	5360 (1205)	0.152 (0.006)	6.35 (0.25)	505 (0.77)
818-06F	5458 (1227)	0.127 (0.005)	6.35 (0.25)	538 (0.82)
818-03F	5809 (1306)	0.127 (0.005)	4.83 (0.19)	433 (0.66)
818-04F	5667 (1270)	0.127 (0.005)	9.65 (0.38)	472 (0.72)

Simply Supported Medium				
8 ply on 2 in. platen				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm.(in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
728-02M	1023 (230)	0.076 (0.003)	16.00 (0.63)	85 (0.13)
728-03M	974 (219)	0.076 (0.003)	16.00 (0.63)	79 (0.12)
728-04M	907 (204)	0.051 (0.002)	9.65 (0.38)	52 (0.08)
Quasi Static				
819-01M	734 (165)	0.025 (0.001)	6.35 (0.25)	39 (0.06)
819-02M	907 (204)	0.076 (0.003)	4.83 (0.19)	46 (0.07)
819-07M	1059 (238)	0.152 (0.006)	16.00 (0.63)	79 (0.12)
819-08M	1059 (238)	0.127 (0.005)	19.05 (0.75)	105 (0.16)

16 ply on 4 in. platen				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
727-11M	3723 (837)	PENETRATED		
727-12M	3701 (832)	0.279 (0.011)	28.70 (1.13)	492 (0.75)
727-13M	3670 (825)	0.102 (0.004)	25.40 (1.00)	321 (0.49)
727-14M	2998 (674)	0.051 (0.002)	6.35 (0.25)	171 (0.26)
727-15M	2963 (666)	0.076 (0.003)	19.05 (0.75)	262 (0.40)
Quasi Static				
819-16M	3677 (827)			400 (0.61)
819-17M	3670 (825)	0.102 (0.004)	9.65 (0.38)	308 (0.47)
819-09M	4003 (900)	0.152 (0.006)	31.75 (1.25)	315 (0.48)
819-10M	3777(849)	0.203 (0.008)	31.75 (1.25)	328 (0.50)

48 ply on 12 in.				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
61599-02M	23557 (5296)	0.614 (0.024)	112.13 (4.38)	3214 (4.90)
61599-03M	29496 (6631)	0.205 (0.008)	118.53 (4.63)	3011 (4.59)
Quasi Static				
818-07M	23,878 (5368)	0.635 (0.25)	Numerous cracks	25.80 (4.00)
818-01M	28,304 (6363)			26.38 (4.09)

Simply Supported Stiff				
16 ply on 2 in. platen				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
727-20S	2,922 (657)	0.127 (0.005)	31.75 (1.25)	288 (0.44)
727-21S	2,771 (623)	0.178 (0.007)	35.05 (1.38)	334 (0..51)
727-22S	3,350 (753)	0.102 (0.004)	16.00 (0.63)	269 (0.41)
728-01S	3,051 (686)	0.152 (0.006)	26.92 (1.06)	295 (0.45)
Quasi Static				
819-03S	2,904 (653)	not measurable	1.27 (0.50)	269 (0.41)
819-04S	2,918 (656)	0.178 (0.007)	16.00 (0.63)	328 (0.50)
819-05S	2,758 (620)	0.356 (0.014)	38.10 (1.50)	348 (0.53)
819-06S	2,931 (659)	0.279 (0.011)	30.22 (1.19)	308 (0.47)

32 ply on 4 in.				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm. (in)	Delamination Area mm.^{2} (in.^{2})
727-16S	8,696 (1955)	0.152 (0.006)	38.10 (1.50)	984 (1.53)
727-17S	9106 (2047)	0.152 (0.006)	not measurable	1154 (1.76)
727-18S	9,853 (2215)	0.178 (0.007)	not measurable	1141 (1.74)
727-19S	9,346 (2101)	0.152 (0.006)	47.75 (1.88)	1207 (1.84)
Quasi Static				
819-14S	9,866 (2218)	0.330 (0.013)	47.75 (1.88)	1220 (1.86)
819-15S	9,844 (2213)	0.330 (0.013)	47.75 (1.88)	1233 (1.88)
819-12S	10,898 (2450)	0.254 (0.010)	41.40 (1.63)	1586 (2.42)
819-13S	10,925 (2456)	0.279 (0.011)	28.70 (1.13)	1614 (2.46)

48 ply on 6 in.				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm. (in)	Delamination Area mm.^{2} (in.^{2})
727-02S	22,121 (4973)	0.279 (0.011)	1.27 (0.50)	3339 (5.09)
727-03S	22,810 (5128)	0.686 (.027)	63.50 (2.50)	4284 (6.53)
Quasi Static				
817-08S	22,726 (5109)	0.457 (0.018)	Numerous cracks	4146 (6.32)
817-09S	22,383 (5032)	1.067 (0.042)	55.63 (2.19)	4146 (6.32)
817-06S	21,476 (4828)	1.497 (0.059)	Numerous cracks	4211 (6.42)
817-07S	20,987 (4718)	1.016 ()0.040)	31.75 (1.25)	3765 (5.74)

Clamped Flex				
8 ply on 6 in. platen				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm (in)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
616-15F	1930 (434)	0.203 (0.008)	85.85 (3.38)	676 (1.03)
616-16F	2148 (483)	0.381 (0.015)	74.68 (2.94)	479 (0.73)
616-17F	1673 (376)	0.051 (0.002)	19.05 (0.75)	112 (0.17)
616-18F	1668 (375)	0.076 (0.003)	22.35 (0.88)	112 (0.17)
Quasi Static				
708-10F	1735 (390)			
708-11F	2277 (512)	0.635 (0.025)	44.45 (1.75)	348 (0.53)
720-07F	1415 (318)	0.152 (0.006)	12.70 (0.50)	92 (0.14)
720-08F	1899 (427)	0.127 (0.005)	9.53 (0.38)	85 (0.13)

16 ply on 12 in.				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
616-01F	6841 (1538)	0.152 (0.006)	41.28 (1.63)	774 (1.18)
616-02F	6921 (1556)	0.127 (0.005)	57.15 (2.25)	741 (1.13)
616-03F	7037 (1582)	0.127 (0.005)	38.10 (1.50)	833 (1.27)
616-04F	7108 (1598)	0.127 (0.005)	42.07 (1.66)	781 (1.19)
Quasi Static				
720-03F	6935 (1559)	0.178 (0.007)	44.45 (1.75)	643 (0.98)
720-04F	6993 (1572)	0.203 (0.008)	44.45 (1.75)	708 (1.08)
720-05F	7357 (1654)	0.152 (0.006)	25.4 (1.00)	715 (1.09)
720-06F	7517 (1690)	0.178 (0.007)	35.05 (1.38)	840 (1.28)

Clamped Medium				
8 ply on 2 in. platen				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
616-37M	1045 (235)	extensive damage		
616-38M	939 (211)	0.229 (0.009)	Numerous cracks	190 (0.29)
728-09M	936 (210)	0.102 (0.004)	22.35 (0.88)	92 (0.14)
728-11M	1036 (233)	extensive damage		131 (0.20)
Quasi Static				
722-03M	1183 (266)	0.076 (0.003)	16.00 (0.63)	66 (0.10)
722-04M	1045 (235)	0.102 (0.004)	9.65 (0.38)	59 (0.09)
722-05M	939 (211)	0.127 (0.005)	6.35 (0.25)	52 (0.08)
722-06M	894 (201)	not measurable	not visible	46 (0.07)

16 ply on 4 in.				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm (in)	Delamination Area mm.^{2} (in.^{2})
616-25M	3634 (817)	0.076 (0.003)	22.23 (0.88)	276 (0.42)
616-26M	3629 (816)	0.076 (0.003)	34.93 (1.38)	348 (0.53)
616-27M	3665 (824)	0.076 (0.003)	38.10 (1.50)	230 (0.35)
616-28M	3728 (838)	0.127 (0.005)	44.45 (1.75)	335 (0.51)
Quasi Static				
708-02M	3705 (833)	0.152 (0.006)	Not measurable	348 (0.53)
708-03M	3679 (827)	0.152 (0.006)	25.4 (1.00)	374 (0.57)
708-04M	3652 (821)	0.152 (0.006)	22.35 (0.88)	308 (0.47)
708-05M	4075 (916)	0.152 (0.006)	16.00 (0.63)	420 (0.64)
708-06M	3857 (867)	0.127 (0.005)	Non measurable	420 (0.64)

48 ply on 12 in.				
Impact				
Specimen ID#	Max Load N (lbf)	Dent Depth mm. (in.)	Crack Length mm. (in.)	Delamination Area mm.^{2} (in.^{2})
61599-04M	26823 (6030)	0.794 (0.031)	80.00 (3.16)	3640 (5.55)
61599-05M	23420 (5265)	1.434 (0.059)	70.40 (2.75)	3378 (5.15)
Quasi Static				
817-01M	26293 (5911)	0.333 (0.013)	99.20 (3.88)	4159 (6.34)
817-02M	28290 (6360)	0.435 (0.017)	107.20 (4.19)	3241 (4.94)